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ANALYTIC DETERMINATION OF INTERFERENCE THRESHOLDS FOR MICROWAVE LANDING SYSTEM EQUIPMENT AND TACAN/DME EQUIPMENT

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of

IIT Research Institute
Under Contract to
DEPARTMENT OF DEFENSE
Electromagnetic Compatibility Analysis Center
Annapolis, Maryland 21402

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Interim Report

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16. Abstract

This report analytically estimates the interference thresholds of the Time Reference Scanning Beam (TRSB) Microwave Landing System (MLS) which is comprised of the C-Band angle guidance and the L-Band PDME range guidance equipments. Furthermore, interference thresholds and separation distance requirements of the coexisting TACAN/DME L-Band equipment are determined.

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PDME	ANGLE GUIDANCE		

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PREFACE

The Electromagnetic Compatibility Analysis Center (ECAC) is a Department of Defense facility, established to provide advice and assistance on electromagnetic compatibility matters to the Secretary of Defense, the Joint Chiefs of Staff, the military departments and other DoD components. The center, located at North Severn, Annapolis, Maryland 21402, is under policy control of the Assistant Secretary of Defense for Communication, Command, Control, and Intelligence and the Chairman, Joint Chiefs of Staff, or their designees, who jointly provide policy guidance, assign projects, and establish priorities. ECAC functions under the executive direction of the Secretary of the Air Force and the management and technical direction of the Center are provided by military and civil service personnel. The technical operations function is provided through an Air Force sponsored contract with the IIT Research Institute (IITRI).

This report was prepared for the Systems Research and Development Service of the Federal Aviation Administration in accordance with Interagency Agreement DOT-FA70WAI-175, as part of AF Project 649E under Contract F-19628-78-C-0006, by the staff of the IIT Research Institute at the Department of Defense Electromagnetic Compatibility Analysis Center.

To the extent possible, all abbreviations and symbols used in this report are taken from American Standards Y10.19 (1967) "Units Used in Electrical Science and Electrical Engineering" issued by the USA Standards Institute.

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ENGLISH/METRIC CONVERSION FACTORS

LENGTH

From \ To	cm	m	km	in	ft	mi	nmi
cm	1	0.01	$1x10^{-5}$	0.3937	0.0328	$6.21x10^{-6}$	$5.39x10^{-}$
m	100	1	0.001	39.37	3.281	0.0006	0.0005
km	100,000	1000	1	39370	3281	0.6214	0.5395
in	2.540	0.0254	$2.54x10^{-5}$	1	0.0833	$1.58x10^{-5}$	$1.37x10^{-5}$
ft	30.48	0.3048	$3.05x10^{-4}$	12	1	$1.89x10^{-4}$	$1.64x10^{-4}$
mi	160,900	1609	1.609	63360	5280	1	0.8688
nmi	185,200	1852	1.852	72930	6076	1.151	1

AREA

From \ To	cm^2	m^2	km^2	in^2	ft^2	mi^2	nmi^2
cm^2	1	0.0001	$1x10^{-10}$	0.1550	0.0011	$3.86x10^{-11}$	$5.11x10^{-11}$
m^2	10,000	1	$1x10^{-6}$	1550	10.76	$3.86x10^{-7}$	$5.11x10^{-7}$
km^2	$1x10^{10}$	$1x10^{6}$	1	$1.55x10^{9}$	$1.08x10^{7}$	0.3861	0.2914
in^2	6.452	0.0006	$6.45x10^{-10}$	1	0.0069	$2.49x10^{-10}$	$1.88x10^{-10}$
ft^2	929.0	0.0929	$9.29x10^{-8}$	144	1	$3.59x10^{-8}$	$2.71x10^{-8}$
mi^2	$2.59x10^{10}$	$2.59x10^{6}$	2.590	$4.01x10^{9}$	$2.79x10^{7}$	1	0.7548
nmi^2	$3.43x10^{10}$	$3.43x10^{6}$	3.432	$5.31x10^{9}$	$3.70x10^{7}$	1.325	1

VOLUME

From \ To	cm^3	liter	m^3	in^3	ft^3	yd^3	fl. oz.	fl. pt.	fl. qt.	gal.
cm^3	1	0.001	$1x10^{-6}$	0.0610	$3.53x10^{-5}$	$1.31x10^{-6}$	0.0338	0.0021	0.0010	0.0002
liter	1000	1	0.001	61.02	0.0353	0.0013	33.81	2.113	1.057	0.2642
m^3	$1x10^{6}$	1000	1	61,000	35.31	1.308	33,800	2113	1057	264.2
in^3	16.39	0.0163	$1.64x10^{-5}$	1	0.0006	$2.14x10^{-5}$	0.5541	0.0346	2113	0.0043
ft^3	28,300	28.32	0.0283	1728	1	0.0370	957.5	59.84	0.0173	7.481
yd^3	765,000	764.3	0.7646	46700	27	1	25900	1616	807.9	202.0
fl. oz.	29.57	0.2957	$2.96x10^{-5}$	1.805	0.0010	$3.87x10^{-5}$	1	0.0625	0.0312	0.0078
fl. pt.	473.2	0.4732	0.0005	28.88	0.0167	0.0006	16	1	0.3000	0.1250
fl. qt.	946.4	0.9463	0.0009	57.75	0.0334	0.0012	32	2	1	0.2500
gal.	3785	3.785	0.0038	231.0	0.1337	0.0050	128	8	4	1

MASS

From \ To	g	kg	oz	lb	ton
g	1	0.001	0.0353	0.0022	$1.10x10^{-6}$
kg	1000	1	35.27	2.205	0.0011
oz	28.35	0.0283	1	0.0625	$3.12x10^{-5}$
lb	453.6	0.4536	16	1	0.0005
ton	907,000	907.2	32,000	2000	1

TEMPERATURE

$°C = 5/9\ (°F - 32)$

$°F = 9/5\ (°C) + 32$

FEDERAL AVIATION ADMINISTRATION
SYSTEMS RESEARCH AND DEVELOPMENT SERVICE
SPECTRUM MANAGEMENT STAFF

STATEMENT OF MISSION

The mission of the Spectrum Management Staff is to assist the Department of State, Office of Telecommunications Policy, and the Federal Communications Commission in assuring the FAA's and the nation's aviation interests with sufficient protected electromagnetic telecommunications resources throughout the world to provide for the safe conduct of aeronautical flight by fostering effective and efficient use of a natural resource--the electromagnetic radio-frequency spectrum.

This objective is achieved through the following services:

- Planning and defending the acquisition and retention of sufficient radio-frequency spectrum to support the aeronautical interests of the nation, at home and abroad, and spectrum standardization for the world's aviation community.

- Providing research, analysis, engineering, and evaluation in the development of spectrum related policy, planning, standards, criteria, measurement equipment, and measurement techniques.

- Conducting electromagnetic compatibility analyses to determine intra/inter-system viability and design parameters, to assure certification of adequate spectrum to support system operational use and projected growth patterns, to defend the aeronautical services spectrum from encroachment by others, and to provide for the efficient use of the aeronautical spectrum.

- Developing automated frequency-selection computer programs/routines to provide frequency planning, frequency assignment, and spectrum analysis capabilities in the spectrum supporting the National Airspace System.

- Providing spectrum management consultation, assistance, and guidance to all aviation interests, users, and providers of equipment and services, both national and international.

EXECUTIVE SUMMARY

The Time Reference Scanning Beam (TRSB) Microwave Landing System (MLS) with Precision Distance Measuring Equipment (PDME) developed by the United States Federal Aviation Administration (FAA) has been selected by the International Civil Aviation Organization (ICAO) as the standardized, international, non-visual, precision approach and landing system. This system utilizes two frequency bands; C-Band (5.00 - 5.25 GHz) for the 200 angle-guidance channels and L-Band (960-1215 MHz) for the 200 range-guidance channels.

For an operational deployment of the MLS with PDME, it will be necessary to assign frequencies to each C-Band and L-Band function at the participating airports in accordance with a prescribed channel plan. The FAA has asked the Electromagnetic Compatibility Analysis Center (ECAC) to develop a channel assignment model for the MLS. One of the necessary inputs for developing a channel assignment model is the knowledge of the intra/intersystem interference thresholds of the MLS/C-Band and L-Band equipment as well as the TACAN and DME equipment that operate in the same portion of the L-Band.

Several field and bench tests at the National Aviation Facilities Experimental Center (NAFEC) are planned for experimentally determining the interference thresholds. Meanwhile, the Federal Aviation Administration has requested that the Electromagnetic Compatibility Analysis Center analytically estimate the interference thresholds of the MLS and TACAN/DME equipments so that an initial exercising of the MLS Channel Assignment model can be performed. This report documents the analytical estimation of those thresholds.

In the MLS/C-Band avionics equipment, the quality of the aircraft guidance signal in the presence of interference is expressed in terms of the Control Motion Noise (CMN) error for the angle-processing channel and the percentage of valid decodes in the preamble/data channel. Associated error budgets were used in analytical procedures to determine the interference

thresholds for various MLS configurations for the cases of cochannel and adjacent-channel interference at function level and system level. The constraining threshold values were selected from the system level results as inputs for exercising the channel assignment model. The desired-to-undesired interference threshold values were used in conjunction with MLS power budgets, antenna patterns and propagation loss predictions to determine the separation distance required between the C-Band equipments to preclude cochannel and adjacent-channel interference. The analysis results indicated that to preclude adjacent channel interference, the undesired MLS signal should be assigned at least the second adjacent channel. The separation distance requirement to preclude cochannel interference ranged from 82 nmi to 193 nmi for the MLS receiver at altitudes of 2.1 kilofeet to 20 kilofeet, respectively.

Intra-and inter-system interactions were investigated for the L-Band equipment (PDME, TACAN, DME). The interference cases were categorized as four distinct types according to the frequency and the pulse-pair spacing conditions of the interference source. Determination of the interference thresholds was based on one or more factors such as equipment circuit characteristics, previous test data from NAFEC, equipment performance standards and ICAO Annex 10 constraints. The separation distance requirements between the interacting equipment were determined on the basis of these thresholds. The interference threshold (desired-to-undesired signal power ratio) for the on-channel interference cases ranged from 8 dB to 3 dB reflecting the characteristics of AGC and decoder circuits in these equipment. For the off-channel interference cases, the interference thresholds varied from -25 dB to -75 dB depending on the rejection characteristics of the RF/IF and Ferris-discriminator circuits. The constraining interference threshold values for each equipment type were identified for use in the channel assignment model.

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SECTION 1
INTRODUCTION

BACKGROUND

The Time Reference Scanning Beam (TRSB) Microwave Landing System (MLS) is comprised of aeronautical radionavigation equipment operating in C-Band (5031 to 5091 MHz, 200 channels). The C-Band equipment provides angle guidance (i.e., azimuth and elevation angles) to user aircraft along with basic and auxiliary data such as runway identification and runway site conditions. The angle functions are determined by the Scanning Beam (SB) technique wherein the time interval between the "To" and "Fro" pulses is proportional to the angular position of the aircraft with respect to the runway. The data functions are transmitted to all aircraft within the coverage sector using differential-phase-shift-keying (DPSK) modulation. The angle and data functions are time-multiplexed as independent entities such that a single receiver channel in the aircraft receiver may process these functions in any sequence. The TRSB Microwave Landing System, proposed and developed by the FAA, has been selected by the International Civil Aviation Organization (ICAO) as the "standardized international, non-visual, prevision approach and landing systems."

To meet range-accuracy requirements that are compatible with the MLS angle-guidance concept, a new L-Band (960-1215 MHz) Precision Distance Measuring Equipment (PDME) system has evolved. The PDME system is similar to existing conventional DME systems. It utilizes an airborne interrogator and a ground transponder, which interrogates and returns pulse pairs to determine in the aircraft, the slant range from the time delay between the interrogation and the receipt of reply. Increased accuracy is achieved in the PDME system by utilizing a faster rise time on the leading edge of the first pulse of the pulse pair. This allows a better definition of the time of interrogation and the time of receipt of the reply.

It has been proposed that the additional channels for PDME use can be best realized by multiplexing additional pulse-pair spacings onto the L-Band

frequencies already set aside for TACAN and conventional DME use. Implementation of this L-Band PDME concept depends heavily on the rejection by the PDME system of signals with undesired pulse-pair spacings from TACAN and conventional DME, and vice versa.

When the MLS is deployed operationally, it will be necessary to assign frequencies to each C-Band and L-Band function at participating airports, in accordance with a prescribed channel plan. The Federal Aviation Administration (FAA) has requested that the Electromagnetic Compatibility Analysis Center (ECAC) develop a channel assignment model for the MLS. One of the necessary inputs for developing the channel assignment model is a knowledge of the interference thresholds of the MLS C-Band and L-Band equipment as well as the L-Band TACAN and DME equipment. The interference thresholds are normally expressed by the FAA as the ratio of the desired-to-undesired (D/U) signal power levels for various cases of interference. The equipment interactions of concern are intra-system (MLS/C-Band to MLS/C-Band; PDME to PDME; TACAN/DME to TACAN/DME) and inter-system (between PDME and TACAN/DME).

Several field and bench tests at the National Aviation Facilities Experimental Center (NAFEC) are being planned for experimentally determining the D/U thresholds for the equipment interactions mentioned above. The output of this effort will be available at a later date. Meanwhile, the FAA has requested that ECAC review the available information on the MLS equipment, TACAN and DME equipment and to estimate the D/U threshold ratios that can be used for a preliminary exercising of the MLS channel assignment model. Furthermore, the results of such a task will provide valuable insight for comparison and summarization of the measured data gathered in the test program.

The concept, design and operational details of the C-Band equipment and the L-Band equipment are quite different. For example, in the C-Band equipment the angle information is derived in the airborne receiver based on illumination from the ground equipment. The L-Band equipment operates on a

closed-loop basis wherein the airborne interrogator, using a prescribed signal format, solicits navigational information from the ground transponder. Therefore, the details of the interference threshold analysis for the C-Band and the L-Band equipment are different and these are described in two parts.

OBJECTIVE

The objective of this task was to analytically estimate the intra/intersystem D/U interference threshold ratios required for acceptable performance of the MLS angle-guidance and range-guidance equipment as well as for representative L-Band TACAN and DME equipment.

APPROACH

Part I. MLS/C-Band Equipment Interactions

The purpose of a landing system is to assist a pilot and his aircraft in the effort necessary to have a successful touchdown and roll out. This type of performance is assured by keeping the aircraft guidance signal within the prescribed error budget.

The quality of the aircraft guidance signal provided by the MLS/C-Band avionics can be measured in terms of the amount of Control Motion Noise (CMN) present in the guidance signal.[1] The CMN error is a relatively high-frequency perturbation, within the autopilot bandwidth, which affects the aircraft's attitude and induces control surface and column motions which have a negative impact on pilot-acceptance criteria. The total CMN error is dependent on inherent system errors in addition to that introduced by the amount of interference present in the receiver Therefore, the CMN error budget is an essential part of the system design specifications.

[1] Kelly, R.J., Guidance Accuracy Considerations for the Microwave Landing System, Navigational Journal of the Institute of Navigation, Vol. 24, November 3, 1977.

In addition to establishing upper bounds on the CMN errors of processed data, lower limits have been set on the amount of decoded preamble/data that is required for minimum system operation. Therefore, the successful decodeability of DPSK preamble/data is also part of the system design specifications. The lower limit of decodeability is considered to be 72%.[a]

For the Scanning Beam System, separate analytic relationships for cochannel and adjacent-channel interference were used in this analysis to translate the maximum allowable CMN errors at the output of the signal processor into minimum D/U thresholds required at the input of the angle-guidance receiver. In the preamble/data channel, a design-required D/U value necessary for the phase-locked loop ensuring 72% decodeability was used.

In the angle receiver, the adjacent-channel interference was addressed as four separate signal interference combinations; undesired scan-beam interfering with a desired scan-beam; undesired scan-beam interfering with a desired preamble/data; undesired preamble/data interfering with a desired scan-beam; and undesired preamble/data interfering with a desired preamble/data. The D/U values were determined at the function level which characterize the receiver thresholds at the receiver input terminals. These results along with the differences in effective isotropic radiated power between the MLS Configuration/Functions were used to determine the D/U values at the system level. The system level D/U ratios were based on the DPSK channel as a common reference power level. The most constraining D/U value was selected from among the system level results. The constraining D/U value in conjunction with analysis of the worst-case geometry of MLS equipment location was used to determine the channel separation criteria in the adjacent bands.

The cochannel interference was modeled as a multipath type interference and D/U values were determined at the system level. The constraining D/U value along with the predictions of the Institute of Telecommunication

[a]Bendix Letter No. MLS-ICAO-077, dated December 12, 1978.

Services[a] (ITS) propagation loss model were used to determine the distance separation between the systems required to preclude interference.

Part II. L-Band Equipment Interactions

Inter-and intra-equipment interactions were investigated for the PDME, TACAN and DME equipment. Determining the interference thresholds was based on one or more factors such as equipment circuit characteristics, test data, equipment performance standards, etc. The L-Band interference cases were categorized as four distinct types according to tuning and aperture conditions of the interference source. These interference categories are:

Category 1: Cofrequency/Coaperture.[b] The interference threshold estimation was based on the victim receiver automatic gain control (AGC) characteristics, identification function thresholds, interfering couplet service volume geometry and effective radiated power (ERP).

Category 2: Cofrequency/Out-of-Aperture Interference. The interference thresholds were based on decoder characteristics. Furthermore, the field test data was used whenever available.

Category 3: Adjacent Frequency/Coaperture. The interference thresholds were determined from the characteristics of the front-end stages (IF and Ferris-Discriminator Stage).

Catergory 4: Adjacent Frequency/Out of Aperture. The interference thresholds were estimated on the basis of front-end stage characteristics, along with the decoder characteristics.

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[a]The FAA specially requested to use the ITS propagation loss model in this analysis.

[b]Coaperature refers to the presence of an undesired signal with a pulse-pair spacing falling with the victim receiver's decoder aperture (time-domain window).

Intra-PDME interactions were analyzed based on the equipment circuit characteristics. In the case of PDME to TACAN/DME interactions, previously collected data from NAFEC was examined and appropriately modified for establishing the interference thresholds. For intra-DME and inter-TACAN/DME interactions, analysis was performed for developing adjacent-channel protection criteria based on emission spectra derived from ICAO Annex 10 spectral constraints.[2] Equipment protection rules and degradation of the identification function were considered in determining the co-channel interference thresholds.

The results of the aforementioned analysis were summarized in terms of equipment type and D/U thresholds. The separation distance requirements between the interacting equipment were determined. The most constraining D/U ratios for each equipment type were identified for a preliminary exercise of the channel assignment model.

[2] *Aeronautical Telecommunications*, Annex 10, Volume 1, International Civil Aviation Organization, July 1972.

SECTION 2

ANALYSIS

PART I: MLS/C-BAND EQUIPMENT INTERACTIONS

The MLS/C-Band signals can be categorized based on modulation type, as either Scanning Beam (SB) pulsed CW signals or Preamble/Data (PD) DPSK signals. In the airborne MLS receiver, the SB modulation is handled by the angle-processing channel providing information to the pilot/autopilot about various angle functions. As noted in FIGURE 1, the key circuits in the angle-processing channel include a beam envelope detector, a dwell gate processor and a data smoothing filter. Radio frequency (RF) interference and other sytems aberrations degrade the timing measurements in the SB channel and this effect appears as an error signal, called Control Motion Noise (CMN), in the aircraft angle-guidance data. CMN causes undesired perturbations in aircraft attitude resulting in control surface and column motions.

The preamble/data signal uses a differential-phase-shift keying (DPSK) modulation and is handled by the processing channel which includes a phase-locked loop and bit processing circuits. Interference in the PD channel may prevent the phase-locked loop from acquiring lock, or if acquired, may cause it to unlock. Acquisition and decodability of the desired-signal are affected by this phase-locked loop activity. The degradation of the preamble/data signal can take the form of missed decodes primarily due to undesired SB or PD signals. A more detailed system description for the MLS angle-guidance equipment is presented in APPENDIX A.

The MLS angle receiver specifications include an error budget for CMN. This error can be due to RF interference or due to system aberrations. The CMN error due to RF interference can be related to the desired-signal (D) and undesired signal (U) power levels for both the adjacent-channel and cochannel interference cases.

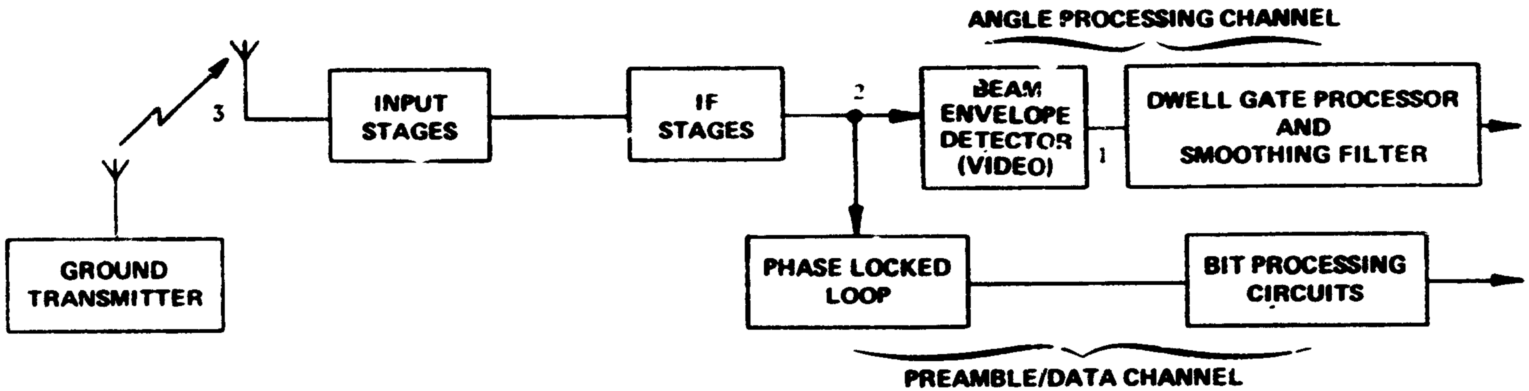

Figure 1a. Simplified block diagram of airborne receiver.

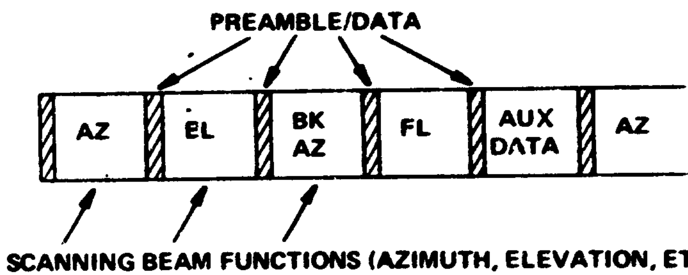

Figure 1b. Time-multiplexed output from the transmitter.

FIGURE 1. MLS/C-BAND EQUIPMENT.

During the course of this analysis effort, three versions of MLS configurations and associated CMN error budgets remained under consideration. All these cases were analyzed for determining the values of interference threshold. The analysis details of two of the cases are given in APPENDIX B. The most representative case discussed in this Section pertains to full capability (FC) and minimum capability (MC) MLS configurations with prescribed CMN error budgets due to RF interference and system aberrations. TABLE 1 lists the parameters for this case.

TABLE 1

MLS CONFIGURATIONS, ANTENNA BEAMWIDTHS (ψ)
AND CONTROL MOTION NOISE (CMN) ERROR BUDGET

Function	Configuration Full Capability	Configuration Minimum Capability
Azimuth ψ	1°	3°
Azimuth CMN	0.1°[a] & 0.2°[b]	0.1° & 0.2°
Elevation ψ	1°	1°
Elevation CMN	0.1° & 0.2°	0.1° & 0.2°

[a]CMN budget due to RF interference

[b]CMN budget due to system aberrations

The analysis procedure for determining interference thresholds due to adjacent-channel interference represents a more general case of analysis. The procedure for analyzing cochannel interference forms a subset of the general case. Therefore, the first part of the analysis effort determines interference thresholds due to adjacent-channel interference.

Adjacent-Channel Interference

The adjacent-channel interference is addressed as four types of signal interference based on various combinations of SB and PD modulations. The interactions considered are interference from (a) undesired SB vs desired SB (U_{SB}-vs-D_{SB}), (b) undesired PD vs desired SB (U_{PD}-vs-D_{SB}), (c) undesired SB vs desired PD (U_{SB}-vs-D_{PD}), (d) undesired PD vs desired PD (U_{PD}-vs-D_{PD}). Equation 1 below (arranged in a logarithmic form) can be used to determine the ratio of desired to undesired signals (D/U) at the receiver processor due to interference in the SB channel.[3] Equation 2, an augmentation of Equation 1, provides the D/U ratio at the receiver input terminals at function level. That is,

$$[D/U]_p = 10 \log \left\{ 0.5 \left[\frac{\Psi}{\Delta\theta}\right]^2 \left[\frac{BW_S}{D_R}\right] \right\} \qquad (1)$$

$$[D/U]_{FAi} = [D/U]_p - 10 \log \left[\frac{BW_I}{BW_V}\right] - A_R \qquad (2)$$

where

$[D/U]_p$ = peak desired-to-average undesired signal power ratio at the processor in the SB channel, in dB

$[D/U]_{FAi}$ = peak desired-to-average undesired signal power ratio at the receiver input terminals for the SB channel, in dB, at function level

$\Delta\theta$ = CMN error budget, in degrees, due to RF interference

Ψ = antenna 3 dB beamwidth of the desired guidance function, in degrees

D_R = data rate, 13.5 Hz for azimuth function and 40.5 Hz for elevation function

BW_S = smoothing filter 3-dB bandwidth, 2.5 Hz

BW_V = video 3 dB bandwidth, 26 kHz

[3] MLS Signal Format and System Level Functional Requirements,, FAA-ER-700-08C, May 10, 1979, p. 146

BW_I = IF bandwidth, 150 kHz

A_R = adjacent-channel rejection, in dB. The rejection is due to RF/IF stages only.

The D/U equation for determining acceptable levels of interference in the preamble/data channel is given as:

$$[D/U]_{PDi} = [D/U]_{PLL} - A_R \tag{3}$$

where

$[D/U]_{PDi}$ = peak desired-to-average undesired signal power ratio at the receivor input terminals for the PD channel, in dB, at function level

$[D/U]_{PLL}$ = peak desired-to-average undesired signal power at the phase-locked loop for successful acquisition of the desired signal, 7 dB and ensuring at least 72% decodeability.

The adjacent-channel rejection factor depends mainly on the emission spectrum from the undesired signal source, the victim receiver's selectivity and the type of interaction (i.e., SB or PD). The curves of adjacent-channel rejection are shown in FIGURES 2 and 3[a] for both modulation types and are based on field test data from the Bendix Co. The theoretical SB emission spectrum from a phased-array antenna is shown in FIGURE 4. The phased-array antenna was considered in this analysis rather than the lens-type, because noise from such an antenna spills into several adjacent channels. The noise is due to the phase-switching action in the beam-steering mechanism. TABLE 2 lists the rejection factors for each type of interaction.

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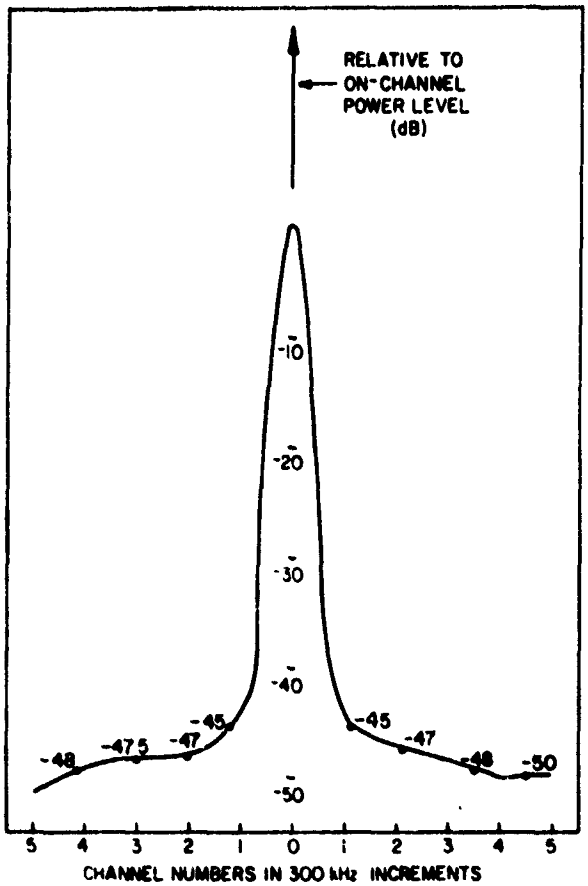
[a]Recent measurements on the current MLS angle receiver at NAFEC indicate that rejection factors for the undesired preamble/data signal are -28 dB, -32.5 dB and -38 dB for the first, second and third adjacent channels respectively. The present analysis does not address this data. However, this data does not impact the main results of the analysis (See Figure 41).



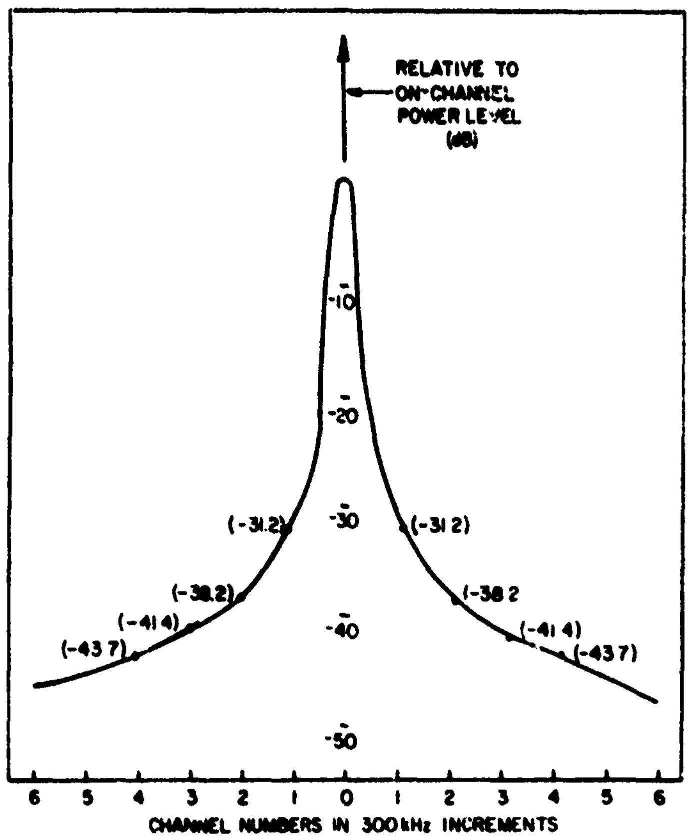
Notes:

(a) This curve is based on Field test data from Bendix Co.; Internal Memorandum No. MLS-ICAO-077, December, 1978.

(b) The adjacent channel power is 'average' power relative to 'peak' on channel power on a long duration basis.

(c) Phased array antenna was used in the ground equipment; Prototype MLS Bendix receiver, (IF bandwidth of 150 kHz), was used for the adjacent-channel interference measurements.

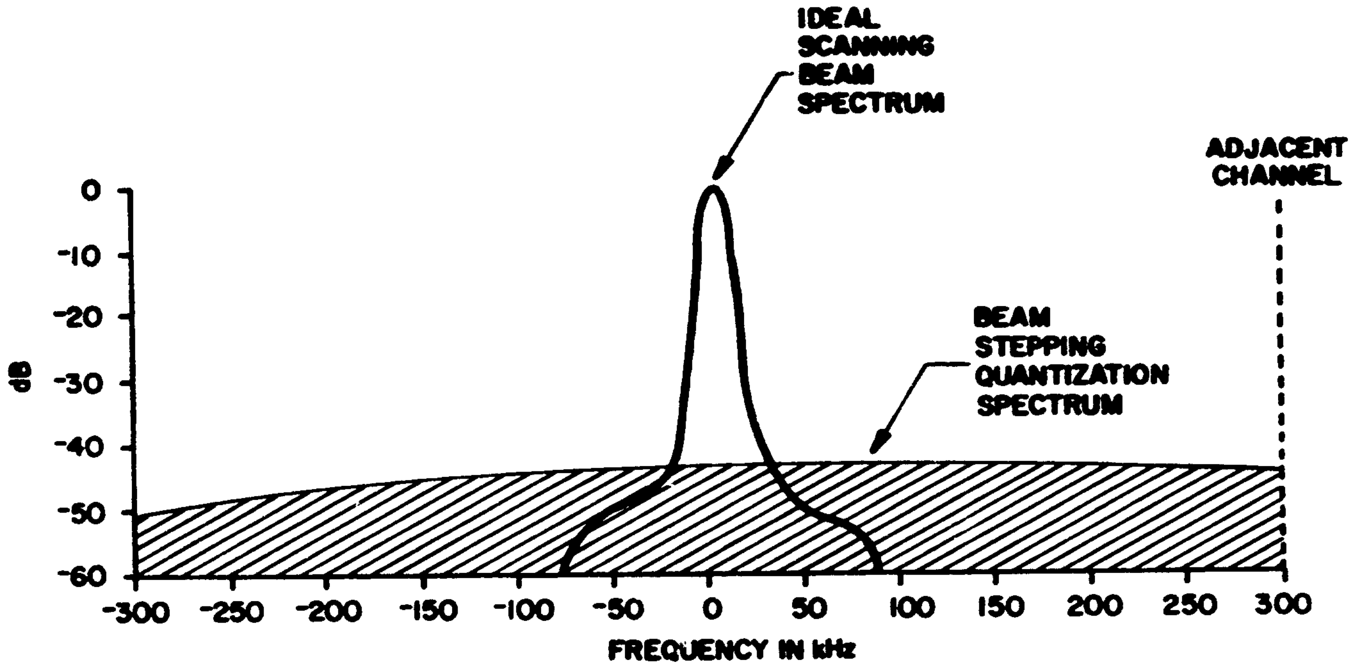
FIGURE 2. SCANNING BEAM SIGNAL LEVEL IN ADJACENT CHANNELS OF ANGLE GUIDANCE RECEIVER.



Notes:

(a) This curve is based on Field test data from Bendix Co.; Internal Memorandum No. MLS-ICAO-077, December, 1978.
(b) The adjacent channel power is 'average' power relative to 'peak' on channel power.
(c) Measurements are referred at the IF circuit output using a prototype MLS Bendix receiver.

FIGURE 3. PREAMBLE/DATA EFFECTIVE SIGNAL LEVEL IN ADJACENT CHANNELS OF ANGLE GUIDANCE RECEIVER.



Notes: (1) Source of curve Bendix Co. Internal Memo for ICAO dated October, 1976

(2) The D/U ratio between peak power on channel signal and 'average power' adjacent-channel signal is about 45 dB. The measurement bandwidth is 150 kHz.

FIGURE 4. SCAN-BEAM EQUIPMENT OUTPUT. (FREQUENCY DOMAIN DATA)

TABLE 2

ADJACENT CHANNEL REJECTION FACTOR (A_R)

Type of Interaction	1st Adjacent Channel Rejection (dB)	2nd Adjacent Channel Rejection (dB)	3rd Adjacent Channel Rejection (dB)	4th Adjacent Channel Rejection (dB)	Comments
U_{SR} vs D_{SR}	45	47	48	50	From FIGURE 2; (Interference level refers to noise floor generated by Phase Shifters in Phase Array Antenna).
U_{SR} vs D_{PD}	45	47	48	50	Same as above.
U_{PD} vs D_{SR}	31.2	38.2	41.4	43.7	From FIGURE 3.
U_{PD} vs D_{PD}	31.2	38.2	41.4	43.7	From FIGURE 3.

Notes: (1) Desired signal is peak power and the undesired signal is average power.
(2) The undesired signal levels are referred at the IF output circuit.

The CMN error budget data in TABLE 1 represents the maximum allowed error due to RF interference and due to system aberrations, respectively. The error budget due to RF interference was used with Equations 1 and 2 for calculating the function level D/U ratios at various stages (e.g. FIGURE 1, terminals 1,2 and 3) in the receiver. The D/U values at the receiver input terminals are summarized in TABLE 3. It may be noted that the function level D/U values (TABLE 3) characterize the receiver thresholds based on prescribed error budgets and these ratios do not take into account the ground equipment parameters at an overall system basis comprising multiple configurations/functions.

The D/U values at the system level consider, in addition, the differences in Effective Isotropic Radiated Power (ΔEIRP) between the receiver guidance functions (i.e., SB, PD) for the interactions betwen the MLS configurations. The ΔEIRP values used in analysis are shown in TABLE 4.

The D/U ratios at the system level are determined from the equation:

$$[D/U]_{si} = [D/U]_{Fi} + X \tag{4}$$

where

$[D/U]_{si}$ = system level D/U ratio at the receiver input terminals, in dB

$[D/U]_{Fi}$ = function level D/U ratios (i.e. $[D/U]_{FAi}$ & $[D/U]_{FPi}$) at the receiver input terminals, in dB

X = adjustment factor, in dB.

The adjustment factor (X) depends on the type of interaction between MLS configuration/function, ΔEIRP values and the reference base chosen for the D/U ratios. In this analysis, the PD channel was chosen as the reference base. The constraining interference threshold selected on the common reference base ensures interference protection for all interacting combinations of MLS configurations/functions. The graphical analysis was performed to determine

TABLE 3

INTERFERENCE THRESHOLDS AT FUNCTION LEVEL FOR FIRST ADJACENT CHANNEL

Type of Interaction	Desired Function	Minimum Capability Configuration D/U (dB)	Full Capability Configuration D/U (dB)
U_{SR} vs D_{SR}	Azimuth	-33.4	-42.9
U_{PD} vs D_{SR}	Azimuth	-19.4	-28.9
U_{SR} vs D_{SR}	Elevation	-38.2	-47.7
U_{PD} vs D_{SR}	Elevation	-24.2	-33.7
U_{SR} vs D_{PD}	Preamble/ Data	-38.0	-38.0
U_{PD} vs D_{PD}	Preamble/ Data	-24.0	-24.0

the adjustment factor (X) for all cases of MLS configurations/functions and the results are summarized in TABLE 5. The function level D/U values (TABLE 3), the adjustment factors X (TABLE 5) along with Equation 4 were used in determining the system level D/U ratios and the results are listed in TABLE 6. An example follows illustrating the procedure for determining system level D/U ratios.

TABLE 4

ΔEIRP VALUES FOR MLS CONFIGURATIONS/FUNCTIONS

Functions / Configurations	ΔEIRP (dB)	
	SB vs PD	PD vs SB
Full capability	17	-17
Minimum Capability	7	-7

The results of TABLE 6 were used to determine the constraining interference thresholds (D/U ratios) at the system level. TABLE 7 lists these ratios. At the system level, the Preamble/Data Channel is therefore more susceptible to interference. Overall, the constraining interference occurs from a Full Capability Scan Beam equipment (as an interferer) to the Preamble/Data channel in victim receiver. The corresponding most constraining D/U ratio is -21.0 dB.

Graphical Format of Analysis:

The CMN error budgets specified separately in TABLE 1 are due to RF interference and system aberrations. Since these errors are considered to be independent variables, the total error can be obtained by the root-sum-square method as shown in Equation 5:

$$\Delta\Theta_T = [(\Delta\Theta)^2 + (\Delta\Theta_S)^2]^{1/2} \qquad (5)$$

TABLE 5

ADJUSTMENT FACTOR (X) FOR TRANSFORMING ADJACENT CHANNEL FUNCTION LEVEL D/U RATIOS TO SYSTEM LEVEL D/U RATIOS

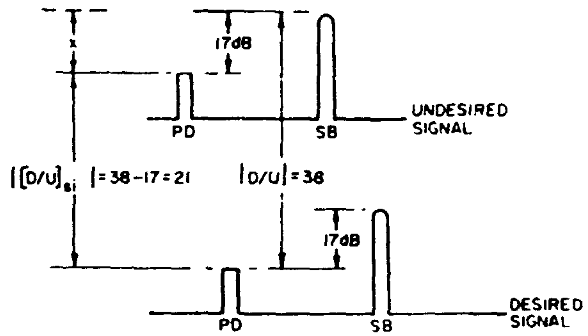
Function / MLS Configurations	X (dB)	
	Intra Function	Inter Function
Intra Configuration	0 (for both SB & PD Functions)	-17 (Desired SB in FC Configuration +17 (Desired PD in FC Configuration -7 (Desired SB in MC Configuration +7 (Desired PD in MC Configuration
Inter Configuration	0 (PD Function) 10 (SB Function)	-17 (Desired FC Configuration) -7 (Desired MC Configuration)

TABLE 6

D/U RATIOS (dB) @ SYSTEM LEVEL

Interacting MLS Configurations \ Functions	$[D/U]_{si}$					
	$U_{SB} V_S D_{SB(AZ)}$	$U_{PD} V_S D_{SB(AZ)}$	$U_{SB} V_S D_{SB(EL)}$	$U_{PD} V_S D_{SB(EL)}$	$U_{SB} V_S D_{PD}$	$U_{PD} V_S D_{PD}$
Undesired Full Capability vs Desired Full Capability	-42.9	-45.9	-47.7	-50.7	-21.0	-24.0
Undesired Full-Capability vs Desired Minimum Capability	-23.4	-26.4	-28.2	-31.2	-21.0	-24.0
Undesired Minimum Capability vs Desired Full Capability	-52.9	-45.9	-57.7	-50.7	-31.0	-24.0
Undesired Minimum Capability vs Desired Minimum Capability	-33.4	-26.4	-38.2	-31.2	-31.0	-24.0

Example: Determine $[D/U]_{si}$ for Full Capability MLS Configuration interacting with Full capability configuration for the case of U_{SB} vs D_{PD}?
With reference to TABLES 3 and 4, the D/U at function level is -38 dB and the ΔEIRP value is 17 dB. These numbers are illustrated in the Figure below: (Remember, D/U ratios have to refer to PD channels). According to this figure, the adjustment factor (x) is 17 dB and that magnitude of system level $[D/U]_{si}$ is 21 dB which agrees with value noted in the above table.



where

$\Delta\theta_T$ = total CMN value in the SB channel processor, in degrees

$\Delta\theta$ = CMN due to RF interference, in degrees

$\Delta\theta_S$ = CMN due to system aberrations, in degrees.

The maximum value of $\Delta\theta_T$ is 0.224° based on Equation 5 and TABLE 1 data.

TABLE 7

CONSTRAINING INTERFERENCE THRESHOLDS AT SYSTEM LEVEL FOR THE FIRST ADJACENT CHANNEL

Interacting MLS Equipment	Interacting Functions	Constraining D/U(dB)
Undesired Full Capability vs Desired Full Capability	U_{SB} vs D_{PD}	-21.0
Undesired Full Capability vs Desired Minimum Capability	U_{SB} vs D_{PD}	-21.0
Undesired Minimum Capability vs Desired Full Capability	U_{PD} vs D_{PD}	-24.0
Undesired Minimum Capabiity vs Desired Minimum Capability	U_{PD} vs D_{PD}	-24.0

The $\Delta\theta$ term can be related to the $(D/U)_p$ ratio (see Equation 1) as shown below:

$$\Delta\theta^2 = 0.5 \frac{\Psi^2}{\mathrm{Ant}[1/10(D/U)_p]} \frac{BW_S}{D_R} \qquad (6)$$

Therefore, $\Delta\Theta_T$ can be related to $[D/U]_{FAi}$ (at receiver input terminals) using Equations 5, 6 and 2; that is,

$$\Delta\Theta_T = \left[(\Delta\Theta_S^{\,2}) + \frac{\Psi^2}{\text{Ant}\left[1/10\left\{(D/U)_{FAi} + 10 \log \frac{BW_I}{BW_V} + A_R\right\}\right]} \frac{BW_S}{D_R} \right]^{1/2} \quad (7)$$

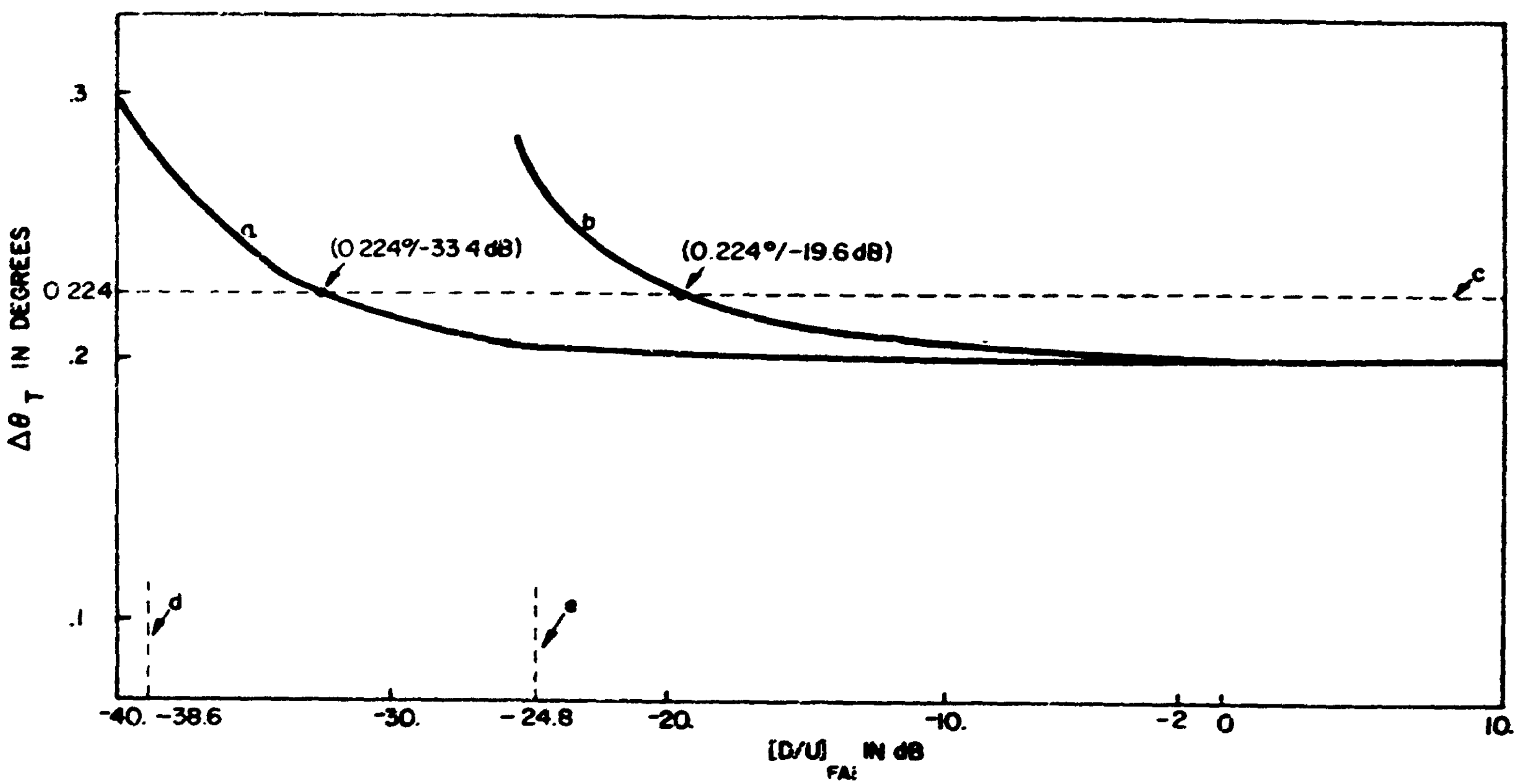
Curves of $\Delta\Theta_T$ vs $[D/U]_{FAi}$ are shown in FIGURES 5 to 8 for the cases of full capability (Ψ = 1°) and minimum capability (Ψ = 3°) MLS configurations.

The plots of FIGURES 5 to 8 can prove useful for interpreting the impact of RF interference and system aberration on the total CMN error. A few salient features of these plots are enumerated as follows.

These figures can be used to provide an understanding of the variation of total CMN error with changes in the ratio of desired to undesired signal power. It can be seen that beyond a certain D/U value (e.g. D/U = -2 dB in FIGURE 5) the contribution to total CMN error due to RF interference is minimal. However, for low values of D/U (e.g. D/U = -10 dB in FIGURE 5 for curve b), the contribution to CMN error from RF interference becomes significant. These curves also can be used to determine interference thresholds (e.g. D/U = -19.6 dB at the intersection of curves b and c in FIGURE 5) at the function level referenced to the receiver input terminals. The bound on D/U values at the receiver terminals is based on a single scan acquisition criterion (i.e., D/U = 14 dB at the signal processing stage;) and is also shown in the FIGURES 5 to 8. It may be noted that for the case of a Full Capability MLS Configuration, the bounds on D/U values based on the single scan acquisition criterion are more pessimistic (e.g. from 4 to 9 dB, in FIGURES 7 and 8) as compared to the D/U values calculated from the prescribed CMN error budget from TABLE 1.

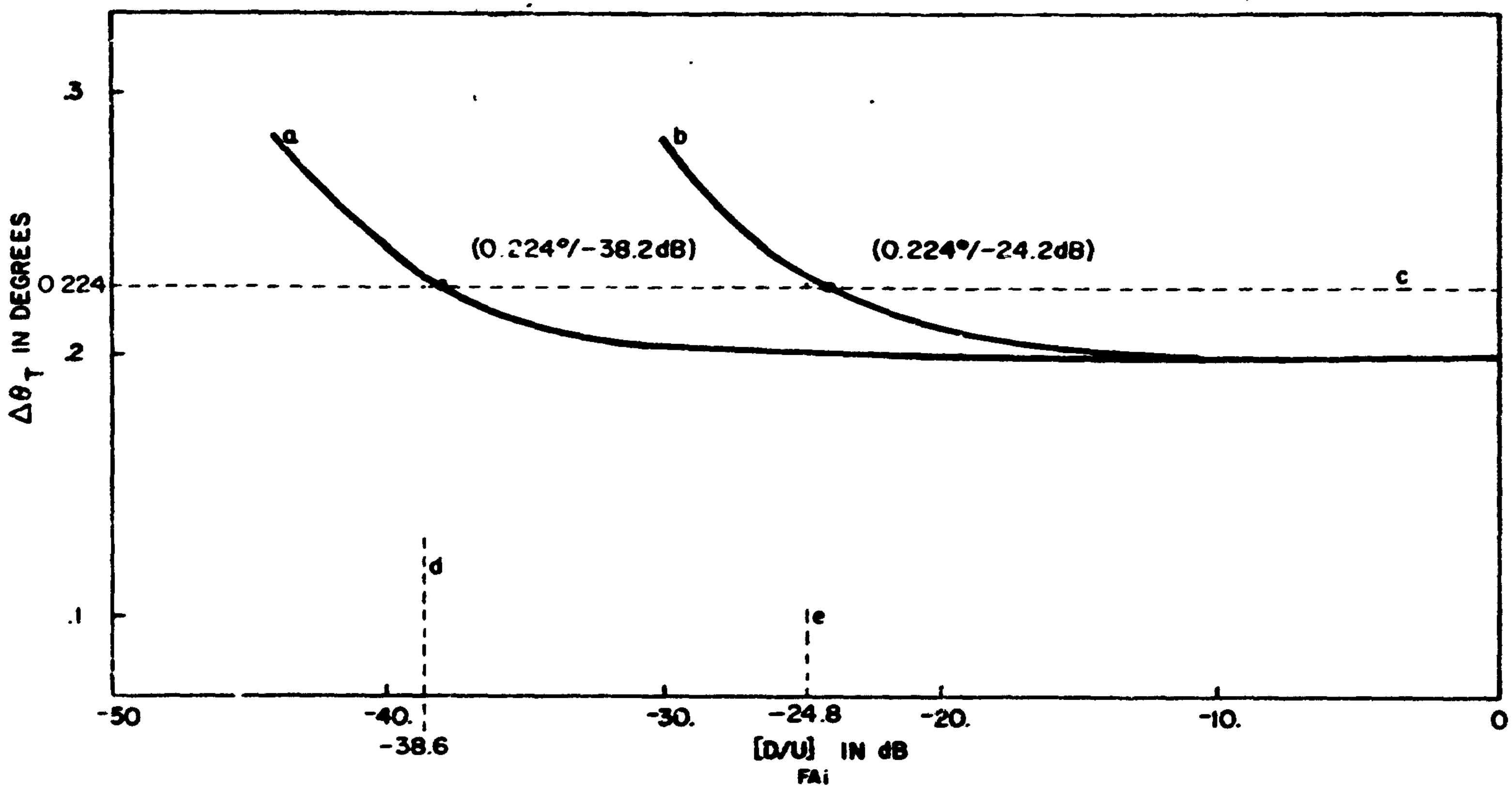
Cochannel Interference

The most severe case of cochannel interference would occur when both the desired and undesired signal functions are nearly time-coincident as shown in



Notes:
(a) Scan Beam-to-Scan Beam Interference
(b) Preamble/Data-to-Scan Beam Interference
(c) Maximum acceptable Level of CMN error
(d) Bound on D/U with Scan Beam interference; based on Single Scan acquisition criteria
(e) Bound on D/U with Preamble/Data interference; based on Single Scan acquisition criteria

FIGURE 5. ADJACENT-CHANNEL INTERFERENCE: MINIMUM CAPABILITY CONFIGURATION; AZIMUTH FUNCTION: $\Delta\theta_T$ VERSUS $(D/U)_{FAi}$



Notes:
- (a) Scan Beam-to-Scan Beam Interference
- (b) Preamble/Data-to-Scan Beam Interference
- (c) Maximum acceptable Level of CMN error
- (d) Bound on D/U with Scan Beam interference; based on Single Scan acquisition criteria
- (e) Bound on D/U with Preamble/Data interference; based on Single Scan acquisition criteria

FIGURE 6. ADJACENT-CHANNEL INTERFERENCE: MINIMUM CAPABILITY CONFIGURATION; ELEVATION FUNCTION: $\Delta\theta_T$ VERSUS D/U_{FAi}

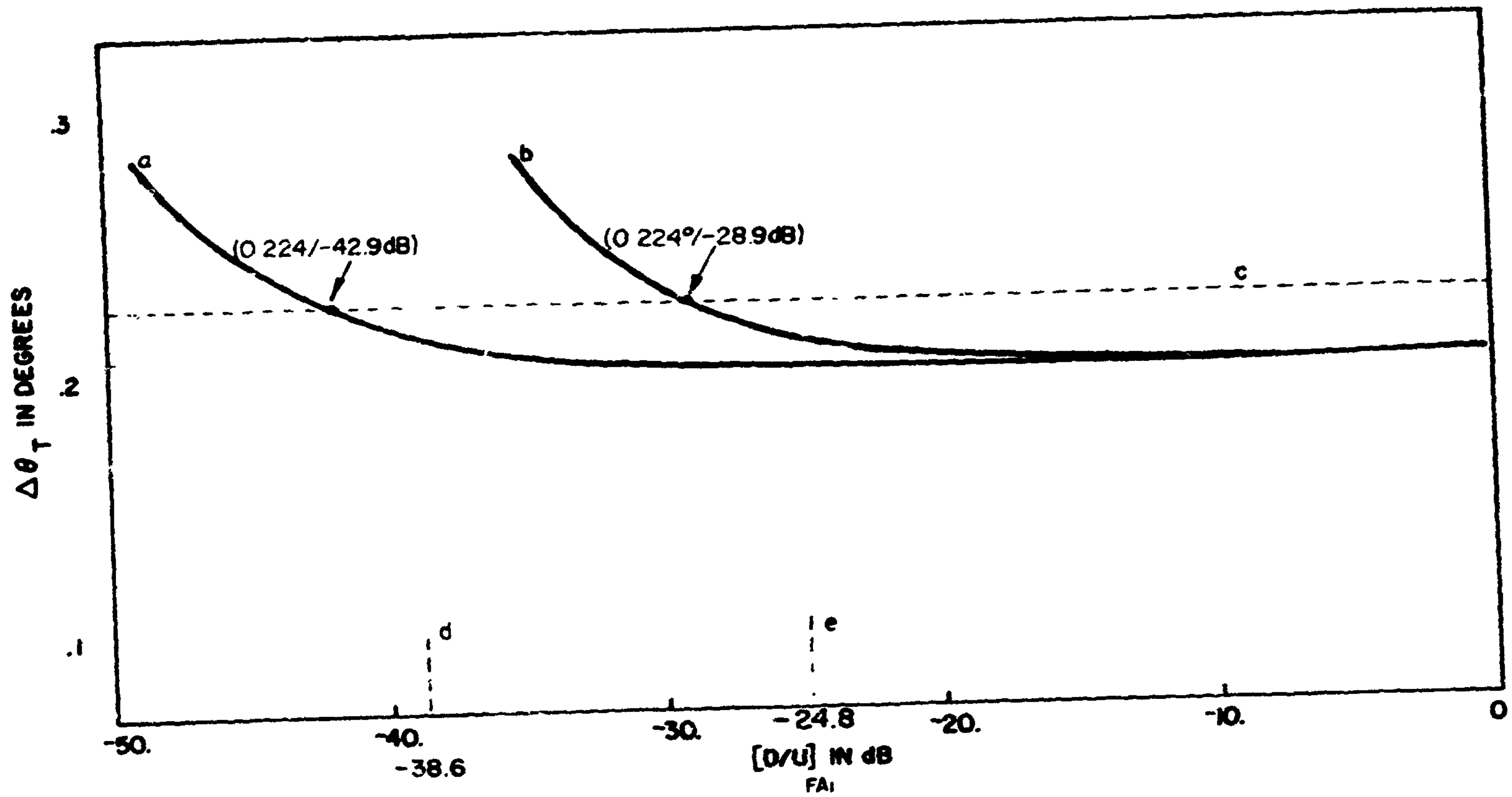
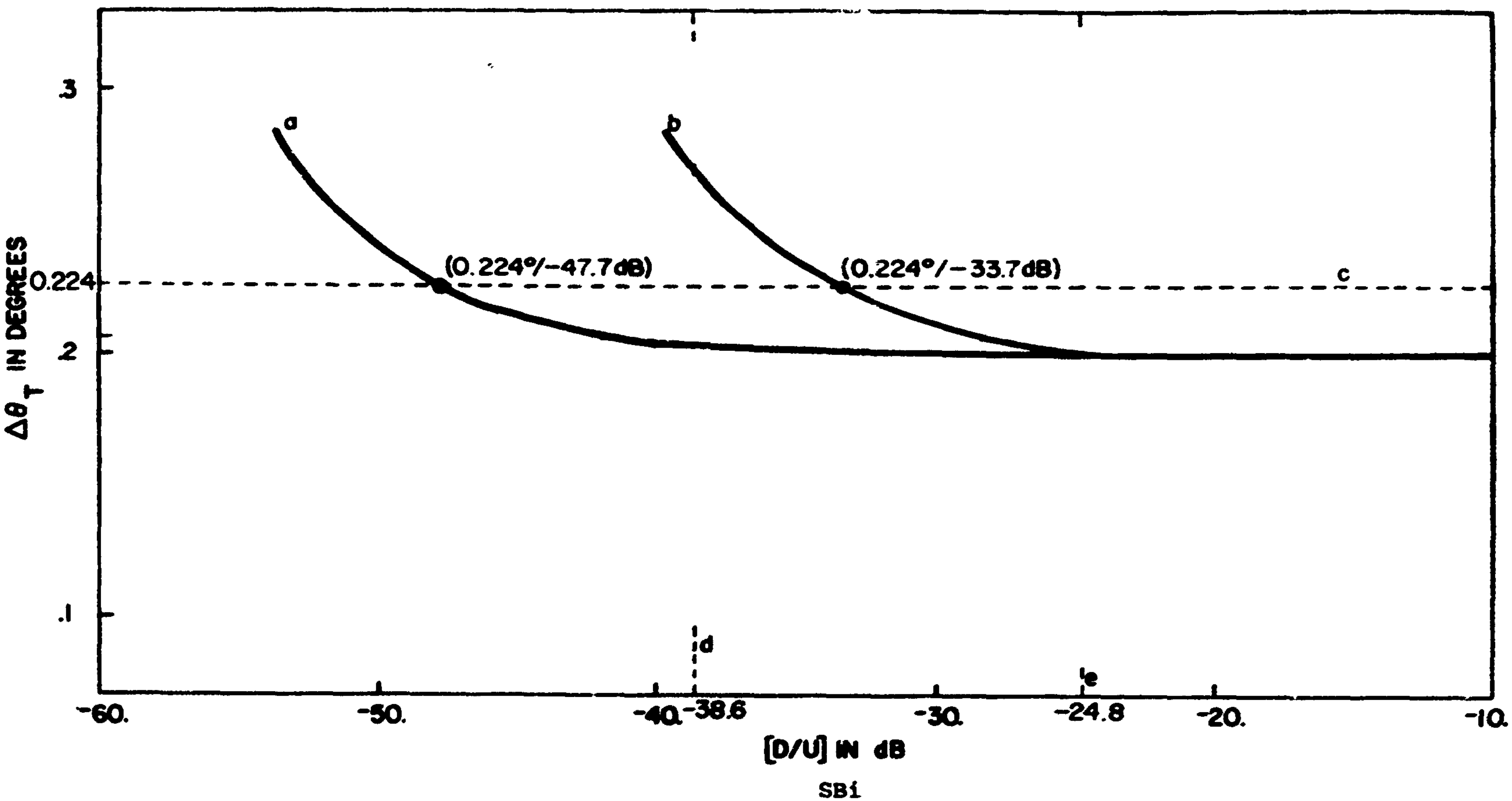


FIGURE 7. ADJACENT-CHANNEL INTERFERENCE: FULL CAPABILITY CONFIGURATION; AZIMUTH FUNCTION: $\Delta\theta$ VERSUS D/U_{FAi}

Notes:
- (a) Scan Beam-to-Scan Beam Interference
- (b) Preamble/Data-to-Scan Beam Interference
- (c) Maximum acceptable Level of CMN error
- (d) Bound on D/U with Scan Beam interference; based on Single Scan acquisition criteria
- (e) Bound on D/U with Preamble/Data interference; based on Single Scan acquisition criteria



Notes:
(a) Scan Beam-to-Scan Beam Interference
(b) Preamble/Data-to-Scan Beam Interference
(c) Maximum acceptable Level of CMN error
(d) Bound on D/U with Scan Beam interference; based on Single Scan acquisition criteria
(e) Bound on D/U with Preamble/Data interference; based on Single Scan acquisition criteria

FIGURE 8. ADJACENT-CHANNEL INTERFERENCE: FULL CAPABILITY CONFIGURATION; ELEVATION FUNCTION: $\Delta\Theta_T$ VERSUS D/U_{FAi}

FIGURE 9. This type of interference situation is similar to multipath-type interference and will result in angle measurement errors. This approach was used in determining interference thresholds for the cochannel case. The equation relating the interference threshold with angle measurement error ($\Delta\Theta$) is approximately expressed as:[a]

$$[D/U]_{CF} \approx 20 \log \left[\frac{\Psi}{\Delta\Theta}\right] - 6 \text{ dB} \qquad (8)$$

where

$[D/U]_{CF}$ = interference threshold at the receiver input terminals for cochannel interference, in dB, at function level.

The CMN error ($\Delta\Theta$) data due to RF interference is given in TABLE 1. The antenna beamwidths (Ψ) are 3° and 1°, respectively for the Minimum Capability and Full Capability MLS configurations. This data along with Equation 8 was used in determining the interference thresholds at the function level and the results are listed TABLE 8.

TABLE 8

COCHANNEL INTERFERENCE THRESHOLDS AT FUNCTION LEVEL

Desired MLS Configuration	$[D/U]_{CF}$(dB)
Full Capability	14.0
Minimum Capability	23.5

The interference thresholds at system level $[D/U]_{CS}$ can be determined by the equation:

$$[D/U]_{CS} = [D/U]_{CF} + Y \qquad (9)$$

[a]Refer to APPENDIX G.

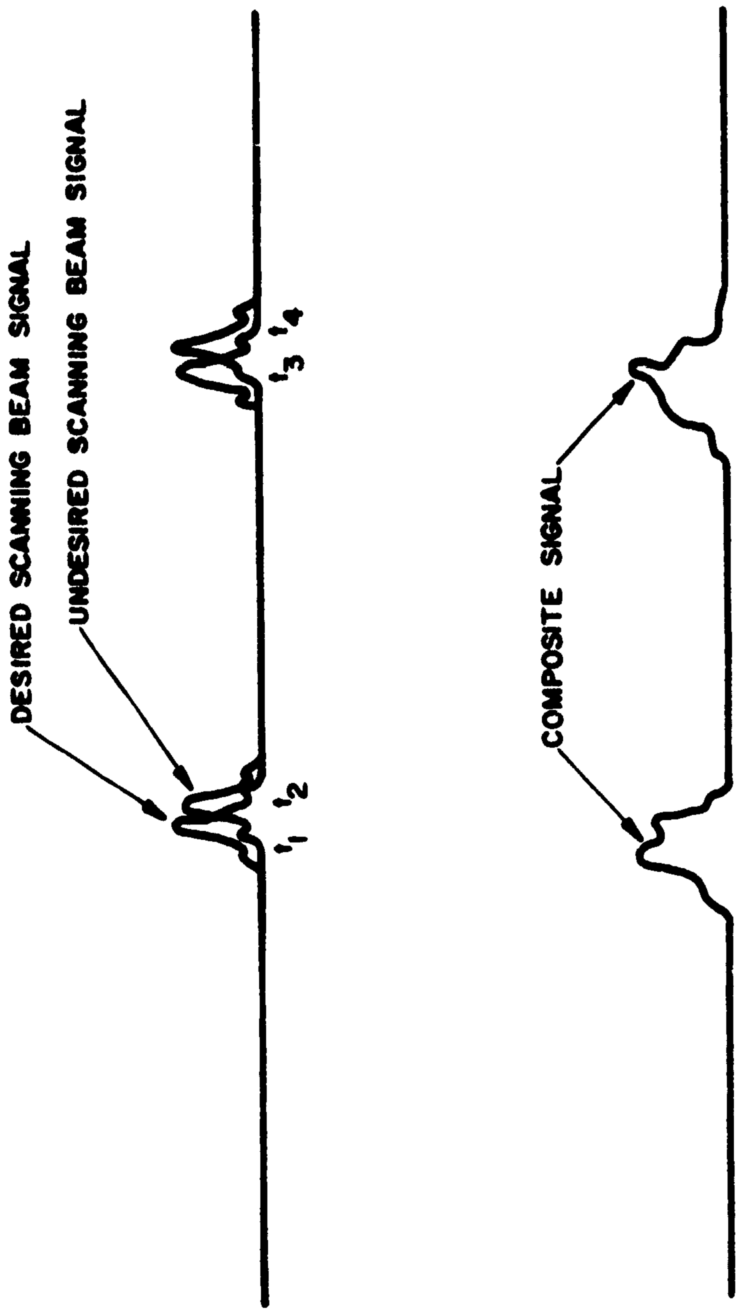


FIGURE 9. PESSIMISTIC CASE OF ANGLE ERROR: IN-BEAM COCHANNEL SCANNING BEAM INTERFERENCE.

where

Y = adjustment factor, in dB.

The adjustment factor (Y) depends on the interacting MLS Configurations, ΔEIRP values and the reference base chosen for the D/U ratios. The graphical analysis for determining Y was performed for all cases of MLS configurations and the results are listed in TABLE 9.

TABLE 9

ADJUSTMENT FACTOR (Y) FOR TRANSFORMING CO-CHANNEL FUNCTION LEVEL D/U RATIOS TO SYSTEM LEVEL D/U RATIOS

Desired MLS Configuration	Undesired MLS Configuration	Y (dB)
Full capability	Full capability	0
Full capability	Minimum capability	10
Minimum capability	Full capability	-10
Minimum capability	Minimum capability	0

The data of TABLES 8 and 9 was used in Equation 9 for determining the D/U values at system level and the results are listed in TABLE 10. The results indicate that at the system level the constraining cases of interference occur when the minimum capability configuration is the interferer. The most constraining D/U ratio is 24 dB and it occurs for the interaction between the undesired minimum capability and desired full capability MLS configurations.

Graphical Format of Analysis: The variation of total CMN error ($\Delta\Theta_T$) with D/U values was examined for the cochannel interference case by plotting the equation:

$$\Delta\Theta_T^{\,2} = 1/4 \; \frac{\psi^2}{[D/U]_{ci}} + \Delta\Theta_s^{\,2} \qquad (10)$$

Equation 10 was derived from Equations 8 and 5. The plots of Equation 10 for the Minimum Capability and Full Capability MLS configurations are shown in FIGURES 10 and 11, respectively. These curves can be used for interpreting the impact of RF interference and system aberrations on the total CMN error trends.

TABLE 10

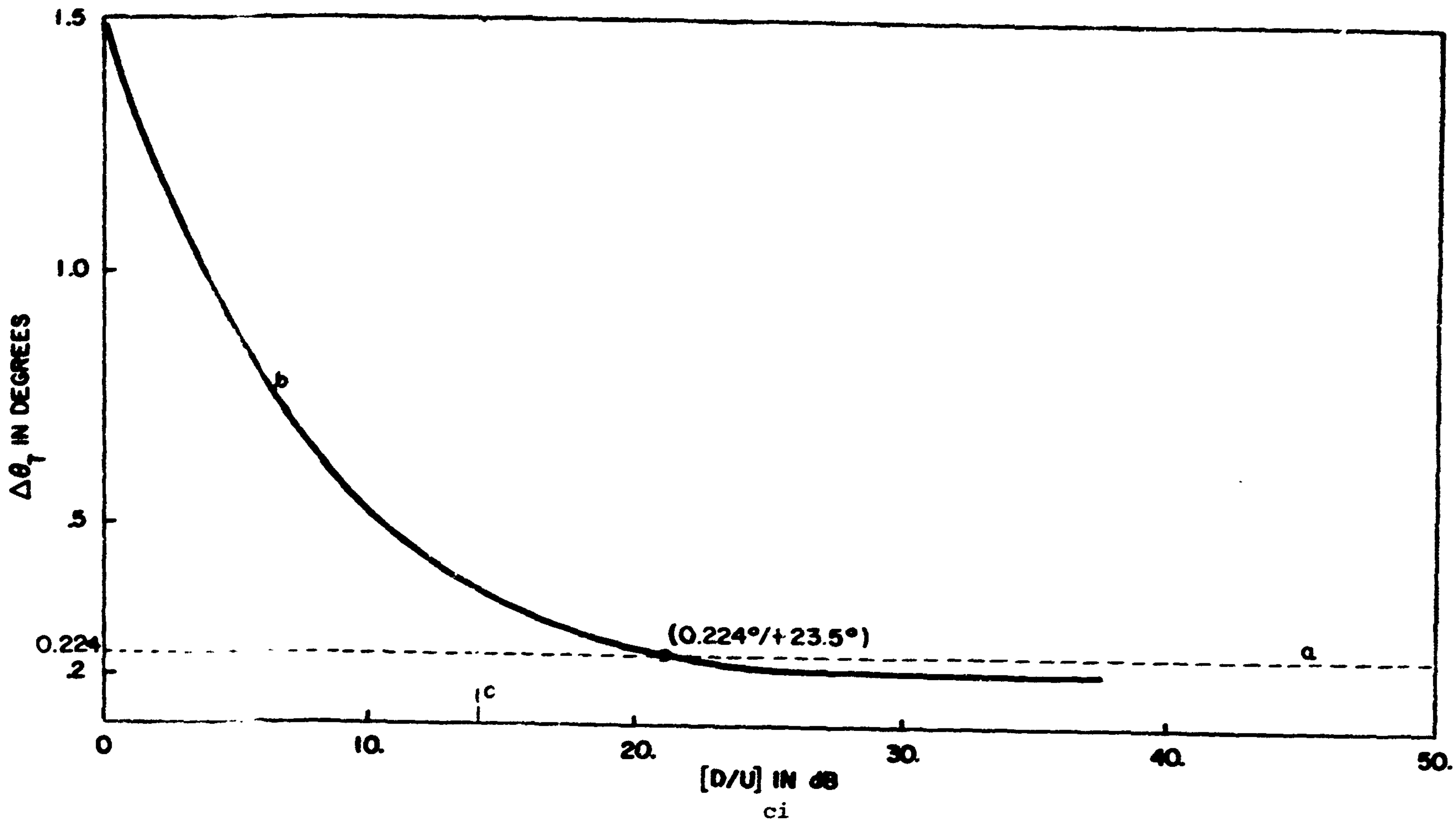
COCHANNEL INTERFERENCE THRESHOLDS AT SYSTEM LEVEL

Interacting MLS Configurations	Interference Threshholds D/U (dB)
(1) Undesired Full Capability vs Desired Full Capability	14
(2) Undesired Full Capability vs Desirad Minimum Capability	13.5
(3) Undesired Minimum Capability vs Desired Full Capability	24
(4) Undesired Minimum Capability vs Desired Minimum Capability	23.5

This section addressed the interference threshold analysis between MLS configurations/functions for the cochannel and adjacent bands. Section 3 of this report summarizes the overall results of this analysis along with the interpretations. These interpretations lead to channel separation criteria for the adjacent-band interference and required separation distance for the cochannel interference. The constraints on these results are also mentioned therein.

PART 2: L-BAND EQUIPMENT INTERACTIONS

From the channel assignment viewpoint, the parameters associated with intra-system and the inter-system interference in the L-Band equipment include



Note (a) Maximum acceptable level of CMN error
(b) Plot of $\Delta\Theta_T$
(c) Bound on D/U with scan beam interference; based on single scan acquisition criteria.

FIGURE 10. COCHANNEL INTERFERENCE: MINIMUM CAPABILITY CONFIGURATION; TOTAL ERROR $\Delta\Theta_T$ VERSUS D/U_{ci}

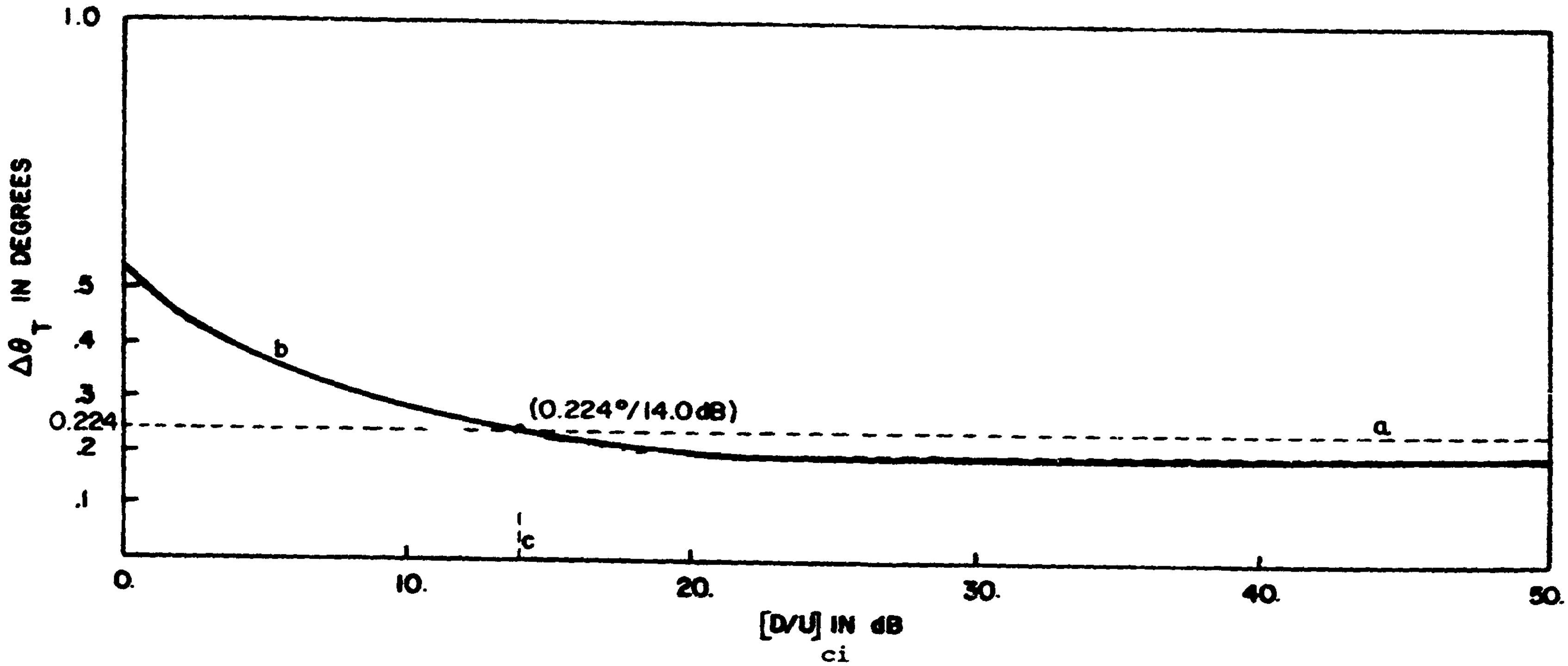


FIGURE 11. COCHANNEL INTERFERENCE: FULL CAPABILITY CONFIGURATION; TOTAL ERROR $\Delta\theta_T$ VERSUS $[D/U]_{ci}$

Notes: (a) Maximum acceptable level of CMN error
(b) Plot of $\Delta\Theta_T$
(c) Bound on D/U with Scan beam interference; based on single scan acquisition criteria.

the signal format, the frequency separation of the desired and undesired signals, pulse-pair spacing, signal amplitude and signal pulse pair repetition frequency (PPRF). Based on these variables, potential interference can be represented in four categories. TABLE 11 shows these categories of interference and the related victim receiver circuit response most likely to reduce the effect of that interference. The characteristics of these key receiver circuits formed the basis of the D/U estimation for most of the interactions that were investigated. The identification of key circuits led to a simplified block diagram (FIGURE 12) that is representative of the L-Band avionics receivers of concern. The overall description of L-Band equipment (TACAN/DME/PDME)[a] is given in APPENDIX C.

TABLE 11

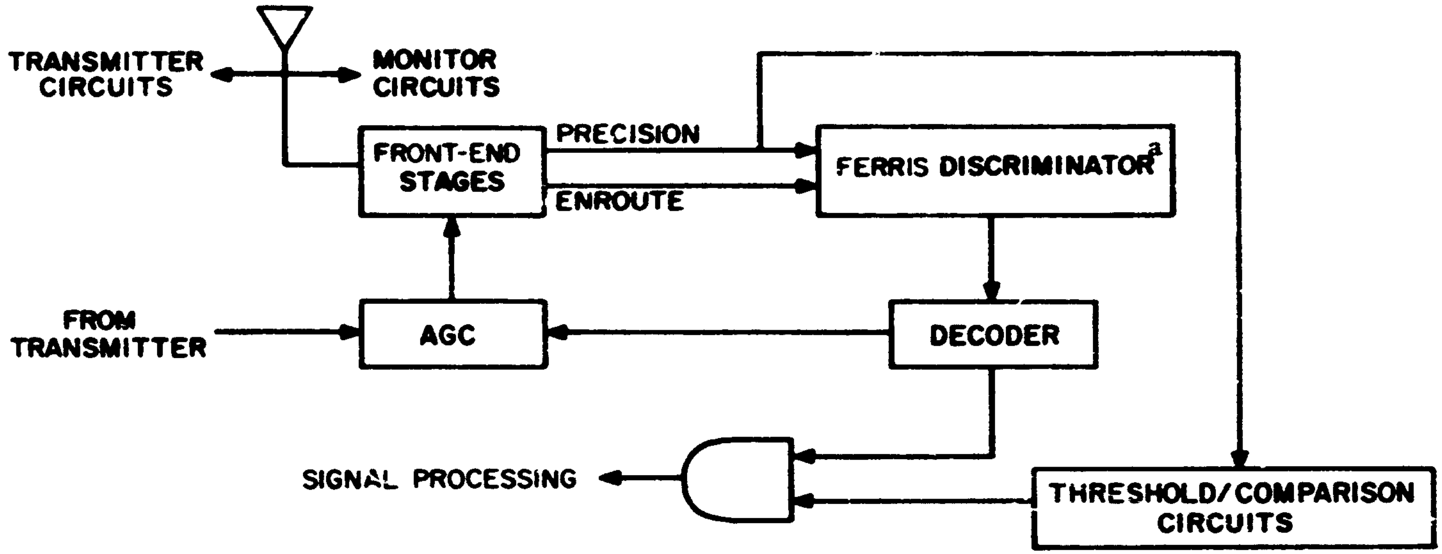
INTERFERENCE CATEGORIES FOR D/U ESTIMATION

Category	Interference Description	Circuit/Response for D/U Estimation	
		Primary	Secondary
1	Cofrequency/ Coaperture	AGC	[a]On-Tune Rejection (OTR)
2	Cofrequency/ Out-of-Aperture	Decoder	OTR
3	Adjacent Frequency/ Coaperture	Ferris Discriminator	[a]Frequency-Dependent Rejection (FDR)
4	Adjacent Frequency/ Out-of-Aperture	Ferris Discriminator	Decoder/FDR

[a]See APPENDIX E.

In an additional analysis in this section, the standard system (TACAN/DME/PDME) parameters such as effective radiated power, service volume geometry and power density (TABLE 12) were examined. These parameters in

[a]In this report, the term DME is used to denote existing conventional DME (e.g., ILS-DME) as opposed to PDME or TACAN.



[a]PDME and King 7000 DME include a conventional type Ferris Discriminator circuit. The PDME in its precision mode has a dual mode Ferris Discriminator circuit with an effective output bandwidth from the Ferris Discriminator having a 7:1 ratio relative to IF (precision) input bandwidth. The conventional Ferris Discriminator comprises a high Q and double tuned circuits with bandwidth ratio about 2:1.

FIGURE 12. SIMPLE BLOCK DIAGRAM OF THE RECEIVER IN AVIONICS EQUIPMENT.

TABLE 12

STANDARD PARAMETERS ASSOCIATED WITH L-BAND AERONAUTICAL RADIONAVIGATION EQUIPMENT[d]

Item	SSV[a]	TACAN Radius	Altitude	SSV	DME Radius	Altitude	DME		PDME	
							SSV	Altitude	SSV	Altitude
1. Service Volume and Shapes	H L T	130 nmi 100 nmi 40 nmi 25 nmi	45,000 ft 60,000 ft 15,000 ft 12,000 ft	H[b] L T	130 nmi 100 nmi 40 nmi 25 nmi	45,000 ft 60,000 ft 18,000 ft 12,000 ft	T(25nmi)	12,000 ft	MLS(20 nmi)	20,000 ft
2. Tx Power		5000 watts			1000 watts		100 watts		100 watts	
3. Gain		7.4 dBi			11.4 dBi		11.4 dBi		8.5 dBi	
4. ERP		44.4 dBW			41.4 dBW		31.4 dBW		25.5[c] dBW	
5. Interrogator Service Volume Power Density (Downlink)		-100.5 dBW/m²			-99 dBW/m²		-99.0 dBW/m²		-92.0 dBW/m²	
6. Transponder Service Volume Power Density (Uplink)		-91.5 dBW/m² above 18,000 ft -86.0 dBW/m² below 18,000 ft			-86.0 dBW/m² below 18,000 ft		-86.0 dBW/m²		(Enroute) -84.0 dBW/m² (Precision)-75.0 dBW/m²	

[a]Standard Service Volume (H-High; L-Low; T-Terminal).

[b]1000 watt DME is not adequate to provide the minimum specified coverage in a Standard Service Volume. In special cases, however, extended coverage may be provided which is comparable to that of a High Altitude Enroute Service Volume. This is referred to as "Extended Service Volume." There are a few higher power DME's (HDME types) presently implemented which can meet the coverage requirements of a High Altitude Standard Service Volume but these operate at power levels on the order of 3 kw.

[c]Includes 3 dB cable loss.

[d]Based on references 3,8,17 and verbal communications from the FAA.

conjunction with propagation loss predictions from the ITS propagation model,[4] were used to relate the determined D/U ratios with the minimum separation distance requirements between the interacting systems. This separation distance between the transponders was interpreted in terms of desired-system service volume radius and the distance to the interferer location from the edge of that service volume. This analysis employs a 95% time availability factor concerning the D/U ratio at the avionics receiver. A brief discussion of transponder interference thresholds is given in APPENDIX F.

The various intra-system and inter-system interactions investigated for L-Band equipment are listed below:

1. PDME-to-PDME
2. PDME-to-DME
3. PDME-to-TACAN
4. TACAN/DME-to-PDME
5. TACAN-to-TACAN
6. DME-to-DME
7. TACAN-to-DME and vice versa.

INTRA-SYSTEM PDME INTERACTION

The PDME avionics equipment operates in the 'precision mode' or in the 'enroute mode.' The 'precision mode' is expected to come into operation when the aircraft is within 5 miles of the landing facility. It is characterized by a lower value of the receiver front-end sensitivity (-74 dBm),[5] using wide bandwidth (3.5 MHz) IF stage and Ferris Discirminator circuits and a threshold level of -20 dB in the delay and comparison circuits. The lower threshold level and wider bandwidth enables one to determine range information with better precision. By comparison, the 'enroute mode' extends from the edge of

[4]Gierhart, G.D. & Johnson, M.E., Propagation and Interference Analysis Computer Program (0.1 to 20 GHz) Application Guide, FAA-RD-77-60, ITS, Boulder, Colorado, March 1978.

[5]Weber, C., Data Sheets, Bendix Avionics Division, Fort Lauderdale, Florida, June 1979.

the service volume to the 5 mile limit. For this mode, the receiver front-end sensitivity is -83 dBm (Reference 5), a narrow bandwidth of 350 kHz and the threshold level is -6 dB. The Ferris Discriminator circuit is not used. The tolerance on range determination is larger for this mode. These modes use the same key circuits identified in the receiver block diagram of FIGURE 12. Therefore, the D/U estimates will be comparable for the two modes.

The Bendix Co. provided the measured characteristics of the key circuits that were used in determining interference thresholds for the PDME avionics. In the circuit measurements, the changes in AGC voltage due to interference were measured, In addition, the leakage of interference decodes into the ranging circuit was monitored by a pulse-counting technique and was expressed as a confidence factor.[a] A high confidence factor indicates a negligible leakage into the ranging circuit. The occurrence of signal break-lock was also monitored and it occurred when the confidence factor fell off. The dynamic range of the PDME was measured to be at least 75 dB based on linear portion of the AGC voltage measurements.

These measurements were, in general, based on allowing the desired signal (set at 12 μs pulse pair spacing) to acquire lock of the receiver. The undesired signal (12 μs or 18 μs depending on the category of interference) was injected into the receiver and its effect was monitored. The intent of these measurements was to get an estimate of the key circuits characteristics.

Category 1 Interference: If the interference is able to pass through the front-end stages (i.e., RF and IF stages), the Ferris Discriminator and the decoder circuits, it may capture/modify the AGC voltage in addition to affecting the range-locking circuit. Category 1 interference (cofrequency and coaperture) penetrates these circuits and the consequent changes in AGC voltage and confidence factor supplied by Bendix are plotted in FIGURES 13 and 14 for the precision and enroute modes, respectively. The probe pair repetition frequency (PPRF) of 1000 represents an intermediate value. With

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[a]Confidence Factor $\triangleq 1 \cdot \left[\frac{\text{Number of leaked pulse pairs}}{\text{Total number of pulse pairs}}\right]$

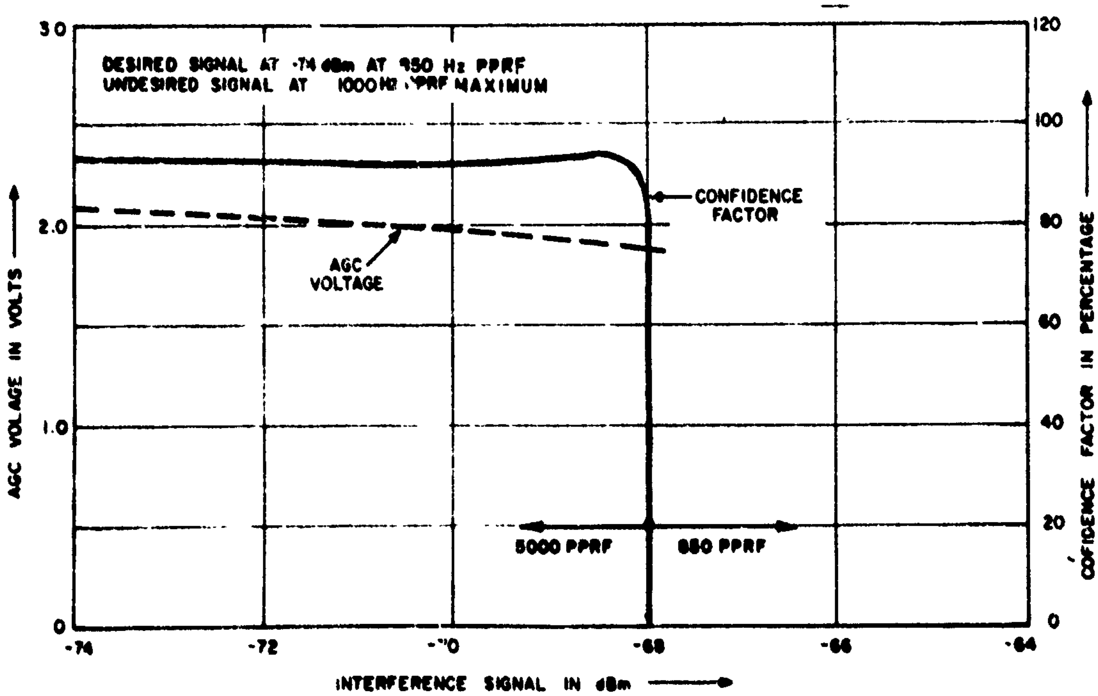

FIGURE 13. PDME (PRECISION MODE) AGC VOLTAGE AND CONFIDENCE FACTOR VERSUS CATEGORY 1 INTERFERENCE SIGNAL.

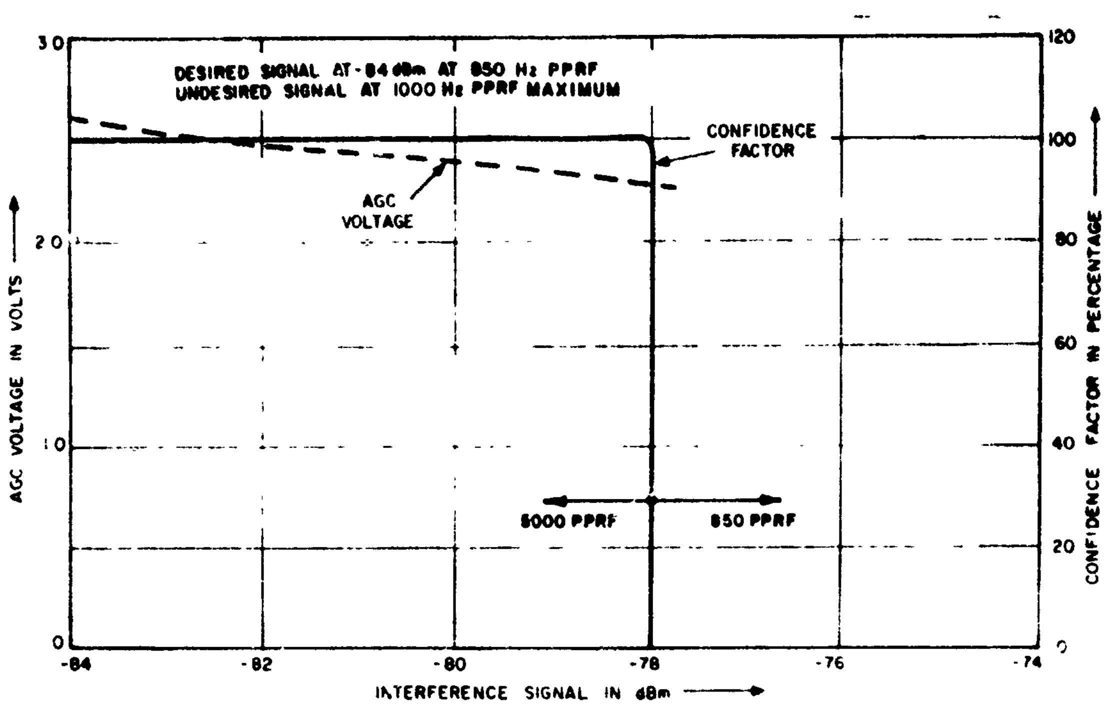

FIGURE 14. PDME (ENROUTE MODE) AGC VOLTAGE AND CONFIDENCE FACTOR VERSUS CATEGORY 1 INTERFERENCE SIGNAL.

higher PPRF (eq. 5000), a smaller level of interference signal will capture AGC and cause break lock.

The data of FIGURES 13 and 14 need proper interpretation regarding D/U value necessary to preclude Category 1 interference in the frequency assignment process. Because a receiver cannot distinguish between which signal is the desired or the undesired, the Bendix data shows that the avionics receiver would always capture the stronger of two signals (similar in waveform) provided the stronger signal is equal to or greater than 6 dB with respect to the weaker signal. This, and only this, is the condition for determining the frequency assignment D/U for Category 1 interference. Such a D/U, provided everywhere within the Standard Service Volume, would assure desired signal acquisition within the specified search time regardless whether an aircraft is flying towards or away from a desired facility. It, therefore, follows that for interference signals, the threshold (D/U) for acquiring range lock (acquisition) is 6 dB. Using PDME system parameters (TABLE 12) and propagation loss predictions from the ITS model, the separation distance between desired and undesired PDME transponder for a D/U of 6 dB is 75 nmi, as shown in TABLE 13. The threshold for break range lock is about 3 dB lower than for acquire-lock based on measurement data for DME avionics taken at NAFEC in 1976[6]. This implies that the D/U threshold for range break-lock is 3 dB, and the minimum separation distance for this threshold is 60 nmi.

The PDME facility identification (Ident), similar to DME, is provided by Morse code signals transmitted at 37.5-second intervals, and consists of groups of pulse-pairs transmitted at a repetition rate of 1350 PPS over the duration of the dots and dashes (Reference 3). The requirements are that equipment shall provide an intelligible and unambiguous output signal identifying the selected ground station for all receiver input signal levels

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[6] Sutton, Mopak, Imhof, The Susceptibility of Representative TACAN and DME Equipment to a Proposed MLS L-Band DME Signal Format, ECAC-PR-77-031, ECAC, Annapolis, MD, July 1977.

down to the receiver sensitivity level[7]. No analytical or experimental study/data has been reported concerning the signal-to-interference ratio (SIR) criteria controlling the potential interaction between two competing, cochannel Ident functions. The 'intelligible and unambiguous' requirement is basically a subjective type of decision. However, it can be assumed that proper identification of a desired Ident signal may require that its power should at least be greater than twice the power (3 dB) of the undesired Ident signal. It therefore follows that a pessimistic D/U value for the Ident function is 4 dB, which includes an additional margin of 1 dB.

TABLE 13

INTRA-SYSTEM PDME INTERFERENCE (CATEGORY 1): SEPARATION DISTANCE RESULTS

D/U (dB)	Total Separation Distance (nmi) Between Transponders	Distance (nmi) of interferer From the Edge of Desired Service Volume
3 (Break lock threshold)	60	40
6 (Acquire lock threshold)	75	55
+4 (Ident Function threshold)	62	42

Comparing the interference thresholds values determined above, the most constraining D/U ratio for Category 1 interference will be selected at 6 dB. TABLE 13 lists the interference threshold values and the separation distance requirements for this case.

[7] Minimum Performance Standards for Airborne Distance Measuring Equipment (DME operating within RF Range of 960-1215 MHz, RTCA Doc. No. Do-151-A, November 1978.

Category 2 Interference: For Category 2 interference (cofrequency/out-of-aperture), the decoder rejection characteristics form the primary basis of the interference threshold. These rejection characteristics (data supplied by Bendix Co.) are implied in the curves of FIGURES 15 and 16 which show the impact of Category 2 interference on the AGC and leakage into the ranging circuits of the PDME receiver while operating in the precision and enroute modes. These curves do not cover the entire dynamic range of the decoder circuit because of limitations in the test setup. However, based on the limited available characteristics, the pessimistic D/U for Category 2 interference is -50 dB for the precision and enroute modes.

Category 3 Interference: In this case, the characteristics of dual-mode Ferris Discriminator (FD) and front-end stages determine the interference threshold values. For example, the curves in FIGURE 17 show rejection characteristics of front-end stages and the dual-mode FD. It can be seen that the wide band front-end stages (i.e., RF and IF stages) alone are not sufficient for suppressing Category 3 interference and the dual mode FD rejection characteristics are essential to ensure protection of the desired PDME signal in precision mode in the presence of adjacent-channel interference. This point is illustrated by the curves 1 and 3 in FIGURE 17. The curve 2 shows the rejection characteristics due to the narrowband circuits and these provide protection from adjacent channel interference in the 'enroute' mode.

The rejection curves 1 and 2 of the front-end stages were obtained by convolving a theoretical emission spectrum (FIGURE 18) of the PDME signal and the selectivity curves (FIGURE 19) for the wideband and narrowband modes of PDME receiver operation. The combined precision mode rejection characteristics (curve 3 FIGURE 17) of the dual mode Ferris Discriminator and front-end stages were based on circuit data supplied by Bendix. The D/U ratios for category 3 interference (FIGURE 17) for the precision mode are -60, -75 dB for the first and second adjacent channels, respectively. Similarly for the enroute mode, the D/U ratios are -37 dB and -49 dB, respectively. The AGC and Confidence Factor data in FIGURE 20 also confirm the precision mode D/U ratio mentioned above.

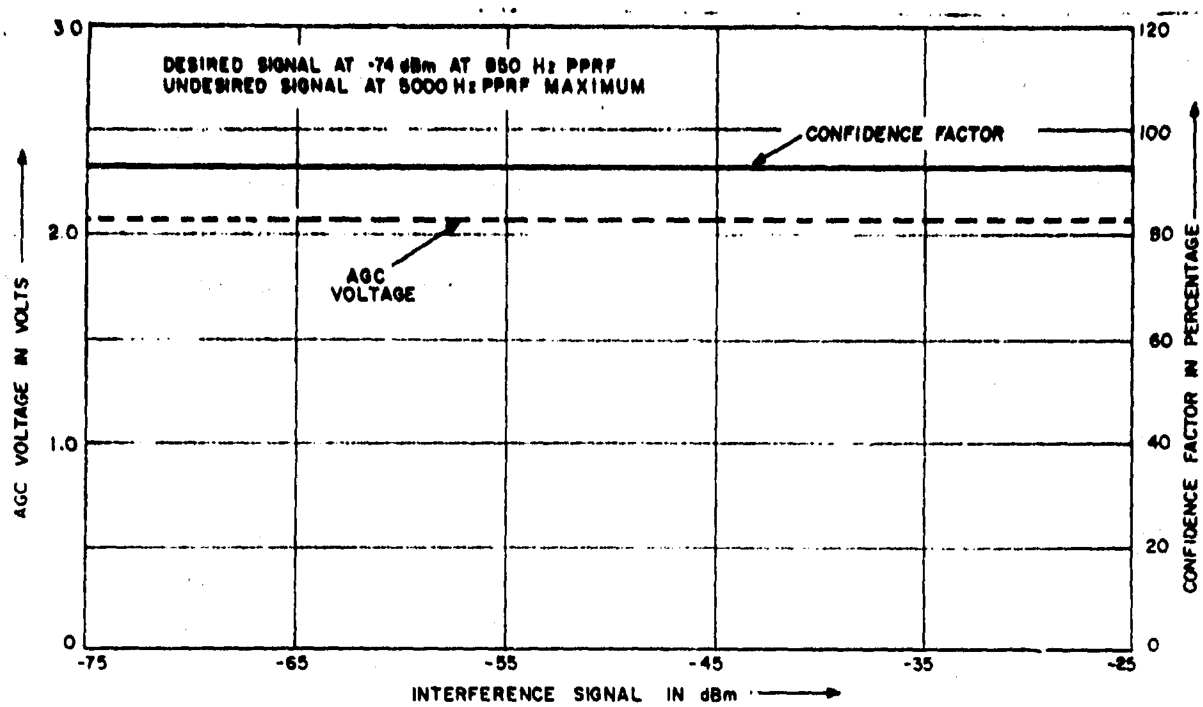


FIGURE 15. PDME (PRECISION MODE) DECODER PERFORMANCE FOR CATEGORY 2 INTERFERENCE SIGNAL.

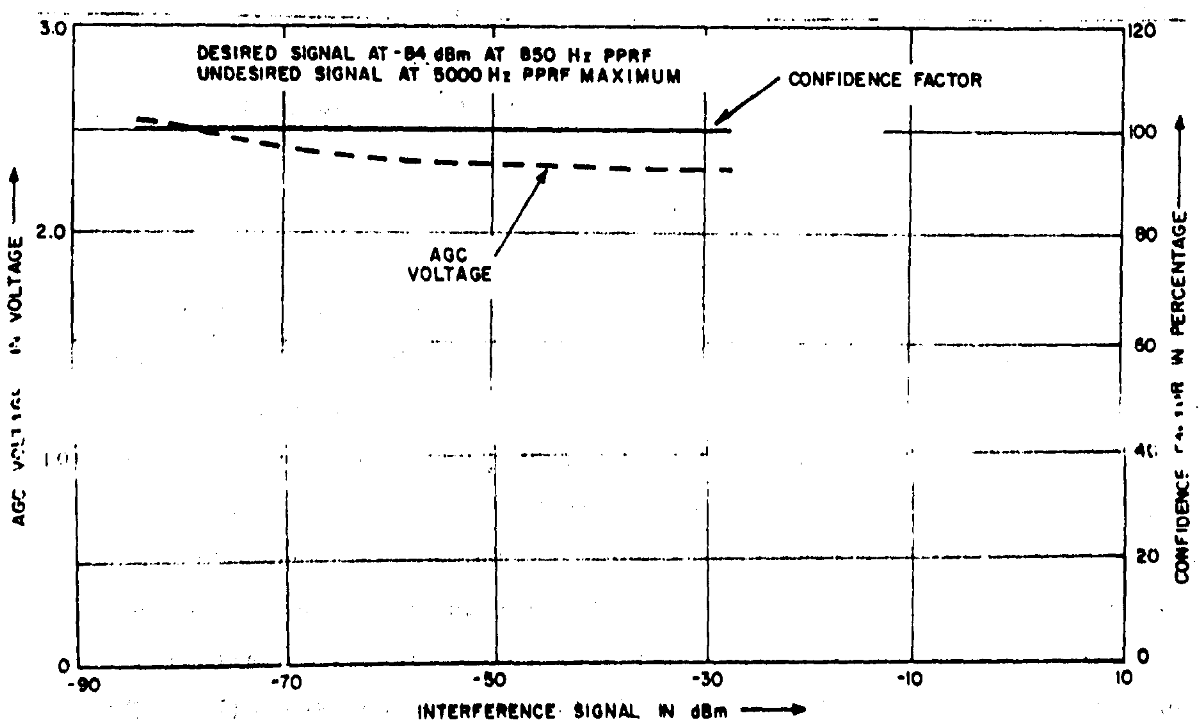
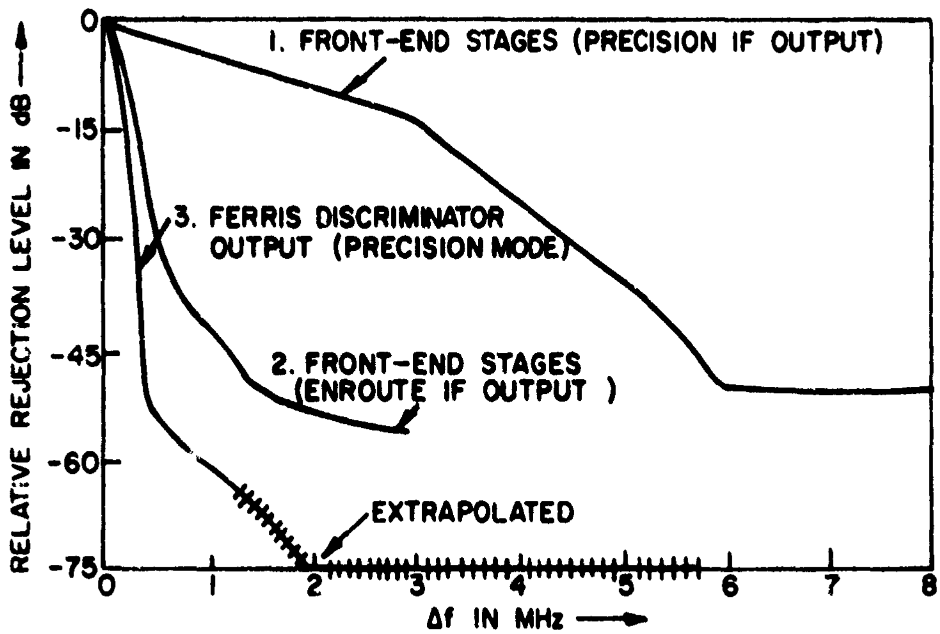


FIGURE 16. PDME (ENROUTE MODE) DECODER PERFORMANCE FOR CATEGORY 2 INTERFERENCE SIGNAL.



Notes:

(1) Δf denotes the change in interference frequency with reference to desired signal frequency

(2) Enroute mode does not utilize the dual-mode Ferris Discriminator in a way similar to the precision mode but employs circuitry which enables it to fashion a bandwidth response much narrower than that of the precision mode.

FIGURE 17. PDME (PRECISION AND ENROUTE MODES): FERRIS DISCRIMINATOR AND FRONT-END STAGE REJECTION CHARACTERISTICS FOR CATEGORY 3 INTERFERENCE.

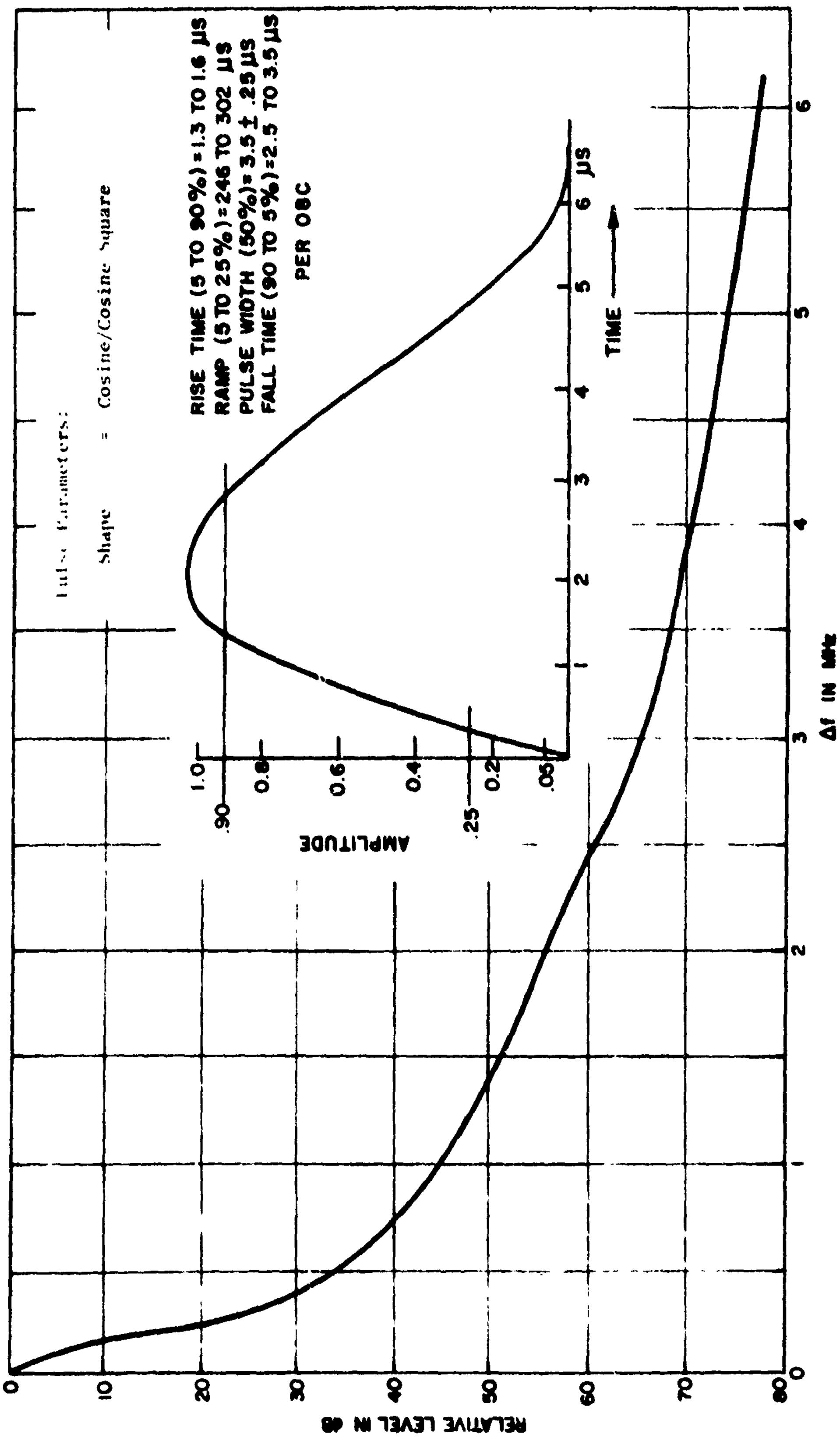


FIGURE 18. PDME EMISSION SPECTRUM THEORETICAL PULSE PARAMETERS.

Category 4 Interference: Low levels of interference signal impinge on the decoder circuit because of the large rejection factor of the front-end stages and the dual-mode Ferris Discriminator. The interference threshold for Category 4 interference for precision mode should be less (more negative) than Category 3 threshold because the low level signals are out of the decoder aperture. Based on the dynamic range of the receiver, the D/U ratio for this case is at least -75 dB. This value also corresponds with the rejection level shown in the FIGURE 17 (curve 3) @ 2 MHz. Similarly the D/U ratio for the enroute mode adjacent channels is -49 dB.

TABLE 14 lists the interference thresholds for intra-system PDME interactions for all of the interference categories discussed above. The interference thresholds derived above are valid to a first order of approximation because the results are based on characteristics of the key circuits in the avionics receiver and not on testing of the entire system. A few conservative approximations in the D/U values were made for the cases (e.g. category 4 interference) for which no characteristics data was available. Overall, the D/U ratios in TABLE 14 are pessimistic values.

PDME INTERFERENCE TO CONVENTIONAL DME

Conventional DME avionics receivers are part of the radionavigational equipment on existing commercial aircraft. The pertinent characteristics of representative DME avionics receivers are shown in TABLE 15. With the exception of the King 7000, none of those equipments use a Ferris Discriminator in the pre-decoder stages. This implies that the front-end stages (i.e., RF and IF stages) alone in conventional DME's need to provide adquate rejection to the adjacent-channel interference from an interfering PDME signal format. This point was verified analytically by convolving a theoretical PDME emission spectrum (FIGURE 18) with a general selectivity curve (APPENDIX D) of the DME. The curve in FIGURE 21 shows the expected protection offered by DME front-end stages from PDME interference.

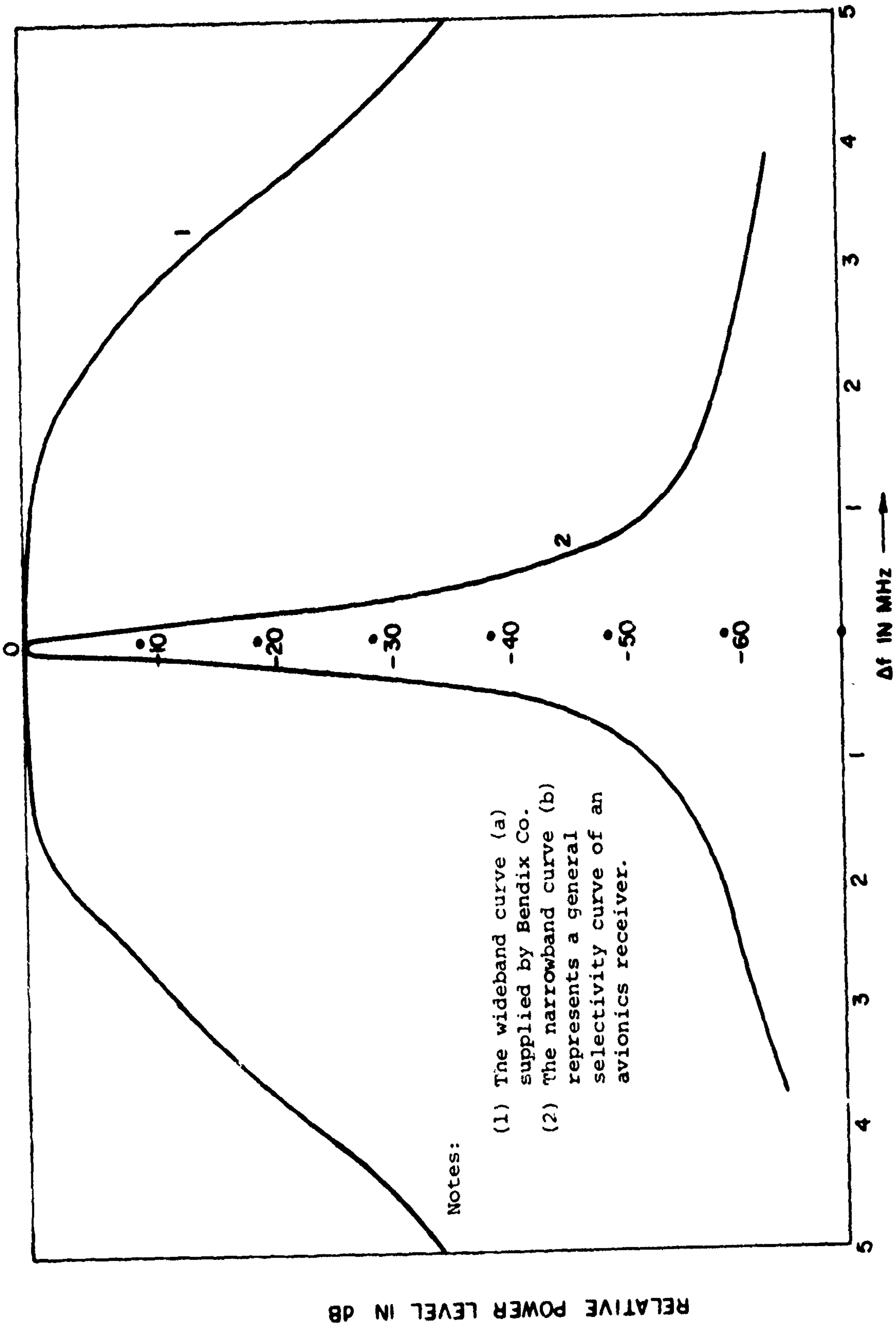


FIGURE 19. PDME SELECTIVITY PLOTS; IF STAGE WIDEBAND AND NARROWBAND CIRCUITS.

TABLE 14

INTRA-SYSTEM PDME INTERFERENCE: INTERFERENCE THRESHOLDS

Interference Category	DU (dB)	Comments
1	3 (Break lock) 6 (Acquire lock) 4 (Ident)	Pessimistic D/U is dB based on acquire lock criteria
2	-50	Pessimistic Value
3	-60, -75 (Precision) -37, -49 (Enroute)	Pessimistic values for the first and second adjacent channels
4	-75, -75 (Precision) -49, -49 (Enroute)	Pessimistic values for the first and second adjacent channels.

The D/U estimates for conventional DME receivers were derived from the acquire-lock test data obtained from NAFEC and documented by ECAC (Reference 6). The raw data was modified/arranged/interpreted as necessary to compensate for the limitations in the test setup. These limitations included deviations in the test spectrum shape, the use of different reference levels of desired signal from equipment to equipment, and not taking the Ident function into consideration.

The data for the first and second adjacent-channel center frequencies was modified by 9 dB and 6 dB, respectively, as shown in TABLE 16. This adjustment was needed because there was difference in the slopes of the simulated test-signal emission-spectrum (FIGURE 22) and the theoretical PDME signal spectrum (FIGURE 18). For comparison purposes, the interference thresholds of DME equipment need to be expressed in terms of a common reference level of the desired signal. This reference was selected as the minimum desired signal (MDS/system) provided by the ground beacon at the end of the operational service volume and is -79 dBm. Another type of desired signal level is the minimum discernable signal (MDS/equipment), which is a measure of a particular equipment sensitivity. The raw data was, therefore, appropriately arranged, plotted, and extrapolated where necessary so that interference thresholds at these power levels could be determined.

TABLE 15

CHARACTERISTICS OF CONVENTIONAL DME AVIONICS

Nomenclature/ Manufacturer	Components	PRF (Hz)	Transmitter Power (kW)	Receiver Dynamic Range (dB)	Decoder Aperture (μs)	Sensitivity (dBm)	Comments
860E-5 (Collins)	Solid State Integrated Circuits (SSIC)	90(S) 22.5(T)	0.316	NA	12 ± 0.5 36 ± 0.5	-90	Typical of forthcoming generation of equipment (AC)
KN65 (King)	SSIC	112 ± 5(S) 21 ± ½(T)	0.100	75	12 ± 0.5 36 ± 0.5	-80	New Equipment (GA)
860F-3 (Collins)	SSIC	75 (S) 18 (T)	1.0	NA	12/30	-93	Typical of current equipment introduced in 1970 for replacing 860E-2 (AC)
DME 190	SSIC	28 (S+T)	0.100	NA	NA	-82	Typical of commercial and general use in future (introduced in 1972 (GA)
UDI-4	Tube	22 (S) 30 (T)	NA	65	NA	-75	NA (GA)
KDM 7000 (King)	SSIC	144 (S) 12/72 (T)	1.0	70	12/30	-90	Introduced in 1970: Representative of large inventory (AC)

Note: NA = Not available, S = search, T = track, AC = air carrier, GA = general aviation.

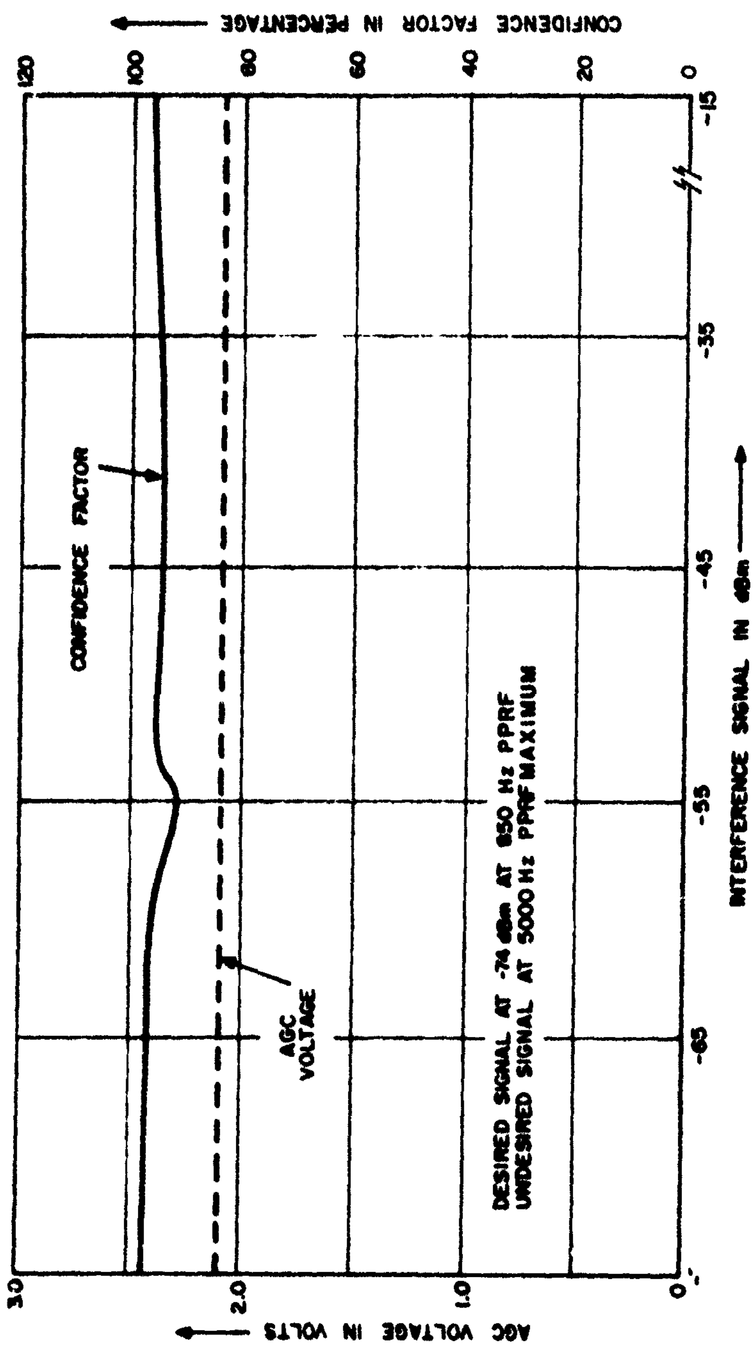


FIGURE 20. PDME (PRECISION MODE): FERRIS DISCRIMINATOR AND FRONT-END STAGES CHARACTERISTICS FOR INTERFERENCE SIGNAL OFFSET BY 1 MHz.

TABLE 16

DIFFERENTIAL[a] LEVELS BETWEEN NAFEC TEST SIGNAL AND THEORETICAL (COS/COS^2) SIGNAL SPECTRUM AT FIRST AND SECOND ADJACENT-CHANNEL CENTER FREQUENCIES

Δf (MHz)	COS/COS^2 Normalized Theoretical Spectrum Level (dB)	NAFEC Normalized Test Signal Level (Worst Case) (dB)	Difference (dB)
1 (1st Adjacent Channel)	-43	-34	9
2 (2nd Adjacent Channel)	-56	-50	6

[a] The normalized levels are not relative to 0.5 MHz bandwidth for both the theoretical and test signal spectrum.

The curves of FIGURES 23 to 29 form the basis of D/U estimates for the DME receiver for Category 1 and Category 2 interference. Similarly, the raw data was processed to obtain interference thresholds for Categories 3 and 4 (FIGURES 29 to 34). These figures are based on NAFEC data using the ARD 300 channel plan[a]. The Category 2 interference data at 18 us pulse pair spacing is pessimistic because the PDME transponder in the Y &XZ modes (See APPENDIX C) transmits at 30 us.

[a]ARD 300 channel plan as defined in Reference 5.

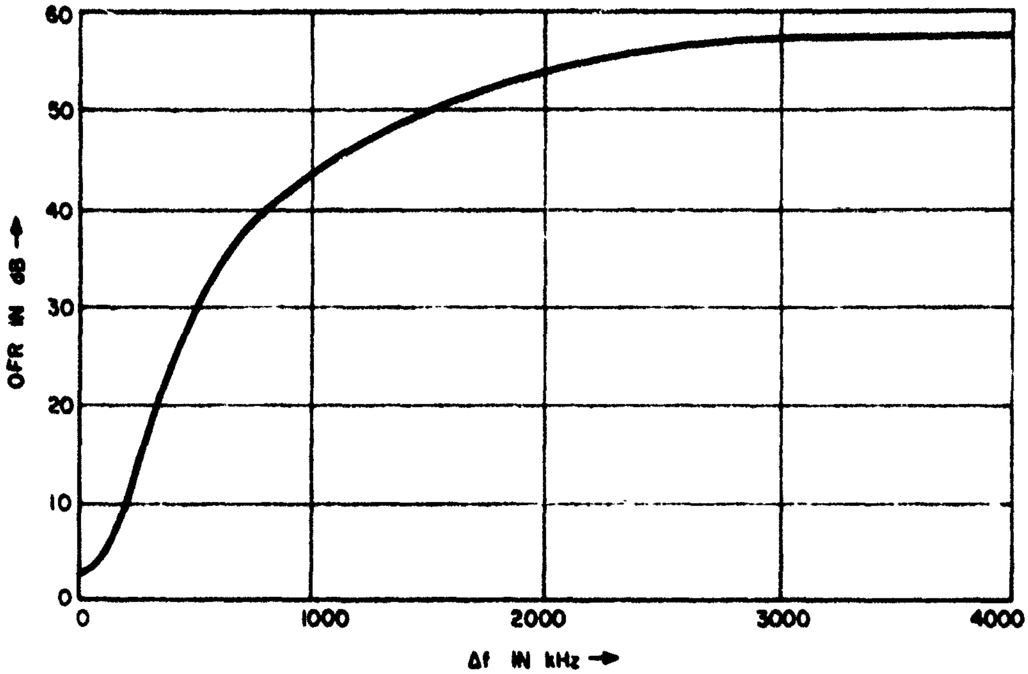


FIGURE 21. PDME VERSUS CONVENTIONAL DME; FDR PLOT. (BASED ON THEORETICAL EMISSION SPECTRUM, FIGURE 18, AND GENERAL SELECTIVITY CURVE, APPENDIX D).

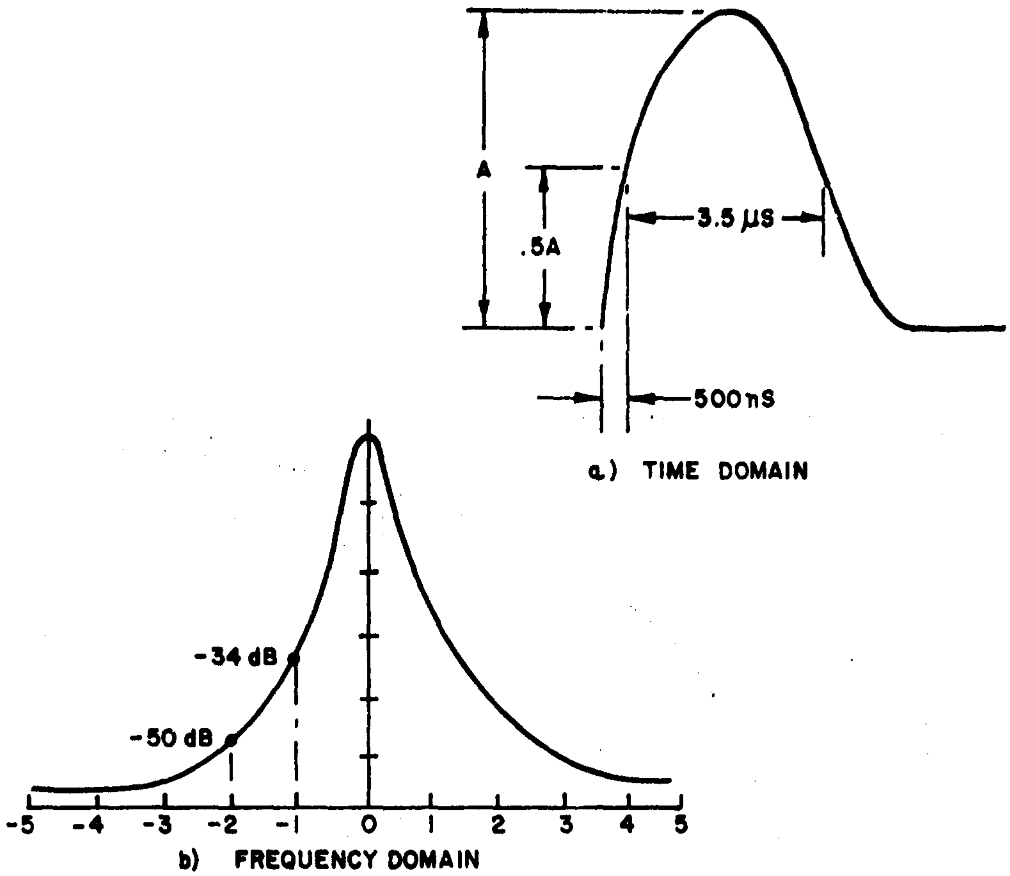


FIGURE 22. SIMULATED PDME TEST SIGNAL SPECTRUM AT NAFEC.
VERTICAL SCALE: 10 dB/div.
HORIZONTAL SCALE: 1 MHz/div.

The resultant D/U estimates for PDME interference to DME receivers are summarized in TABLE 16. These D/U values are based on proper interpretation of the NAFEC data. For example, in the case of Category 1 interference, the D/U ratio was considered to be a positive number because in an intended service volume, the avionics receiver locks on to the stronger desired synchronous signal as previously discussed. The analysis data shows considerable variation in D/U ratios from equipment to equipment for the same category of interference. This variation in D/U ratios is due to differences in circuit performance of these (e.g. front-end sensitivity, IF saturation level, etc.). equipment. The constraining D/U values representative of interference to DME's were determined from this data.

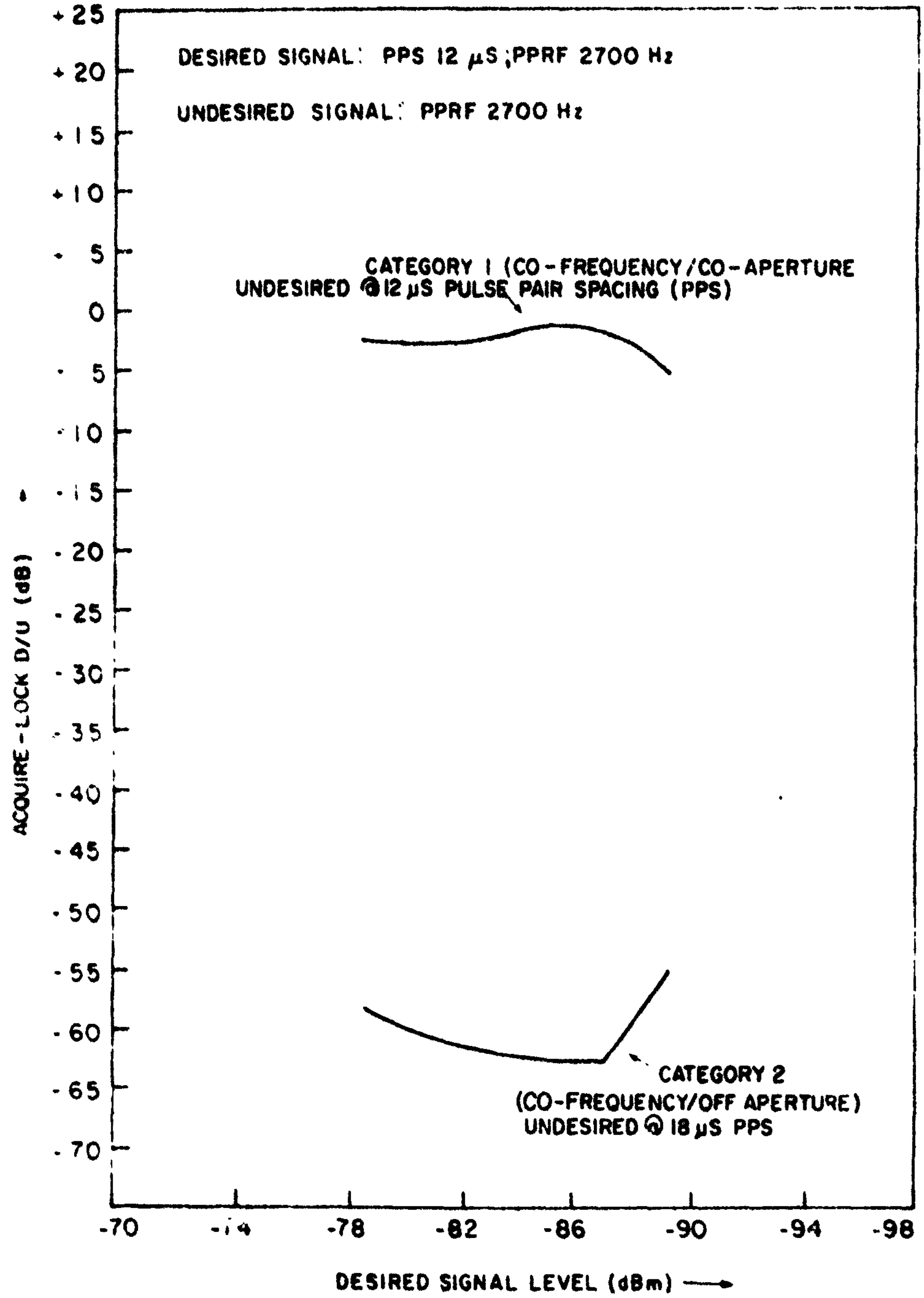


FIGURE 23. COLLINS 860 E-2 EQUIPMENT.

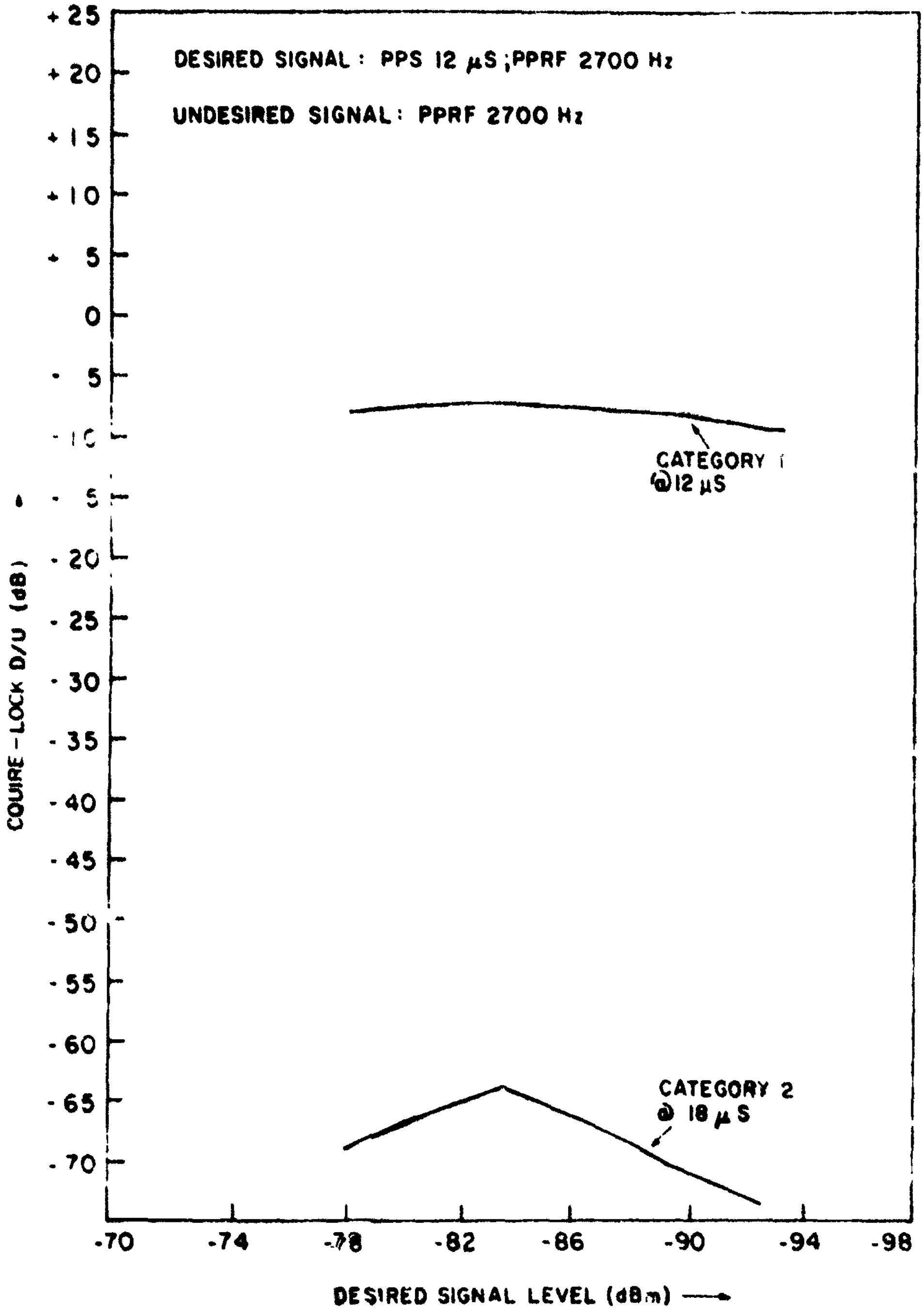


FIGURE 24. COLLINS 860 E-3 EQUIPMENT.

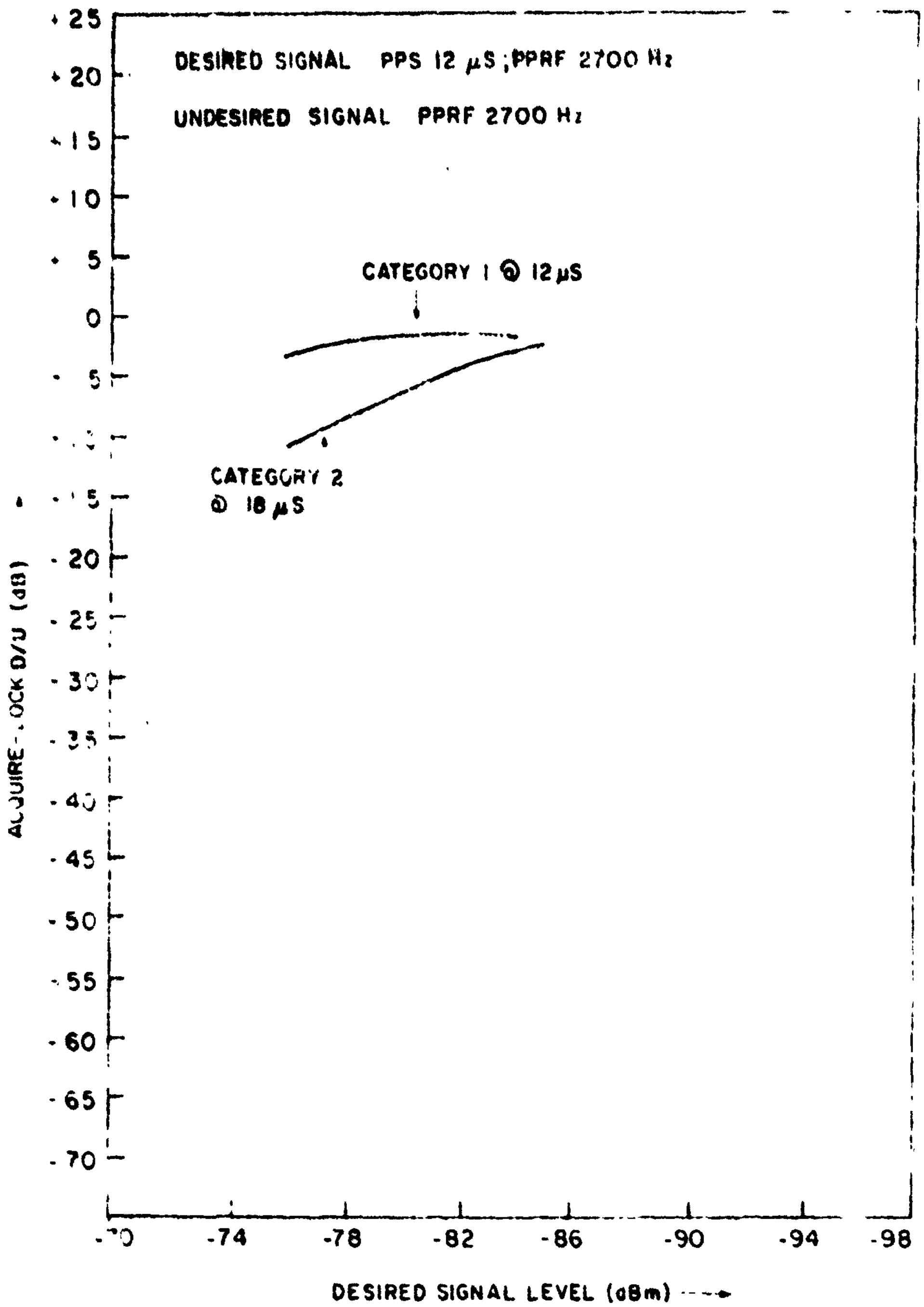


FIGURE 25. KN-60 EQUIPMENT.

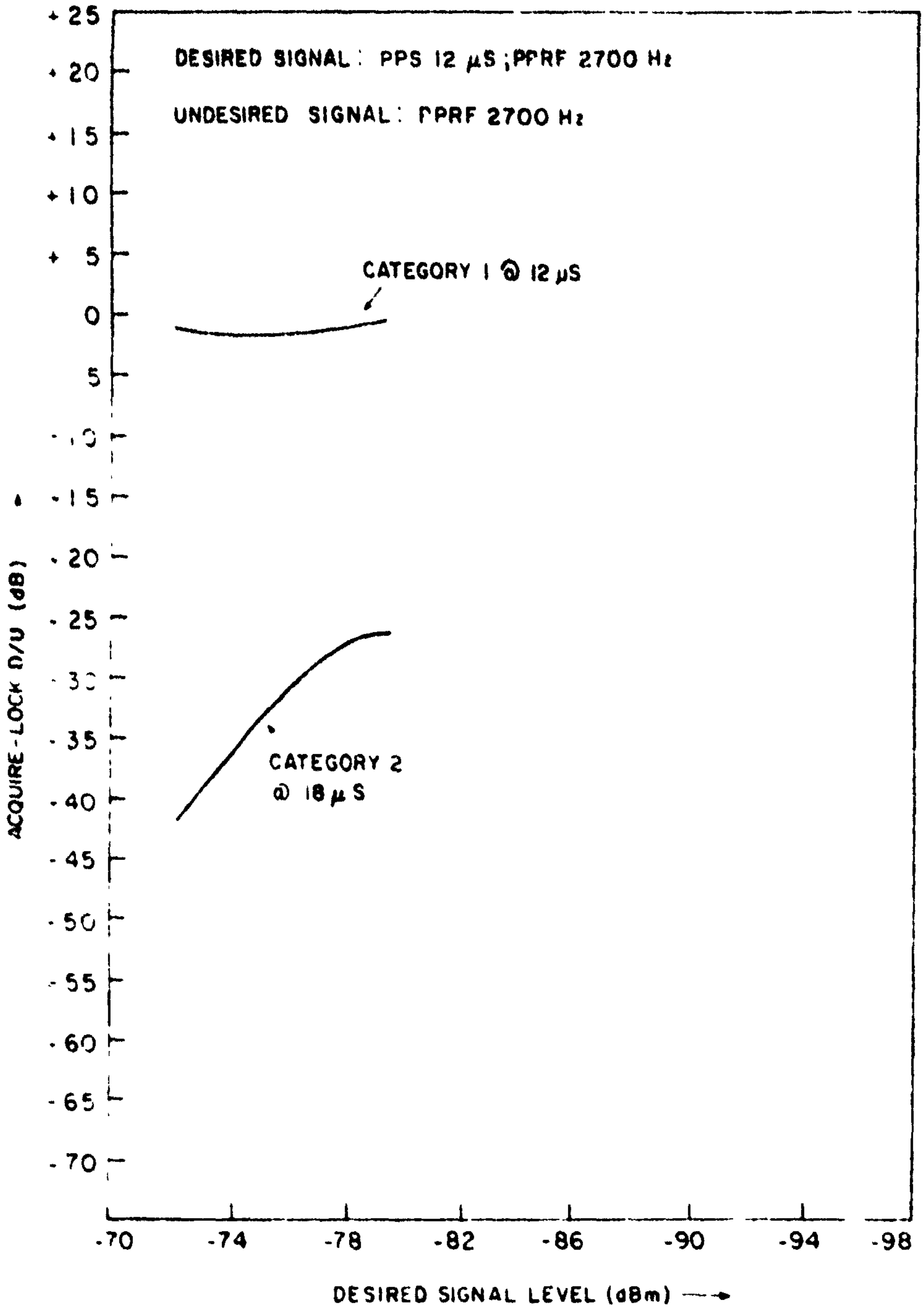


FIGURE 26. KN-65 EQUIPMENT.

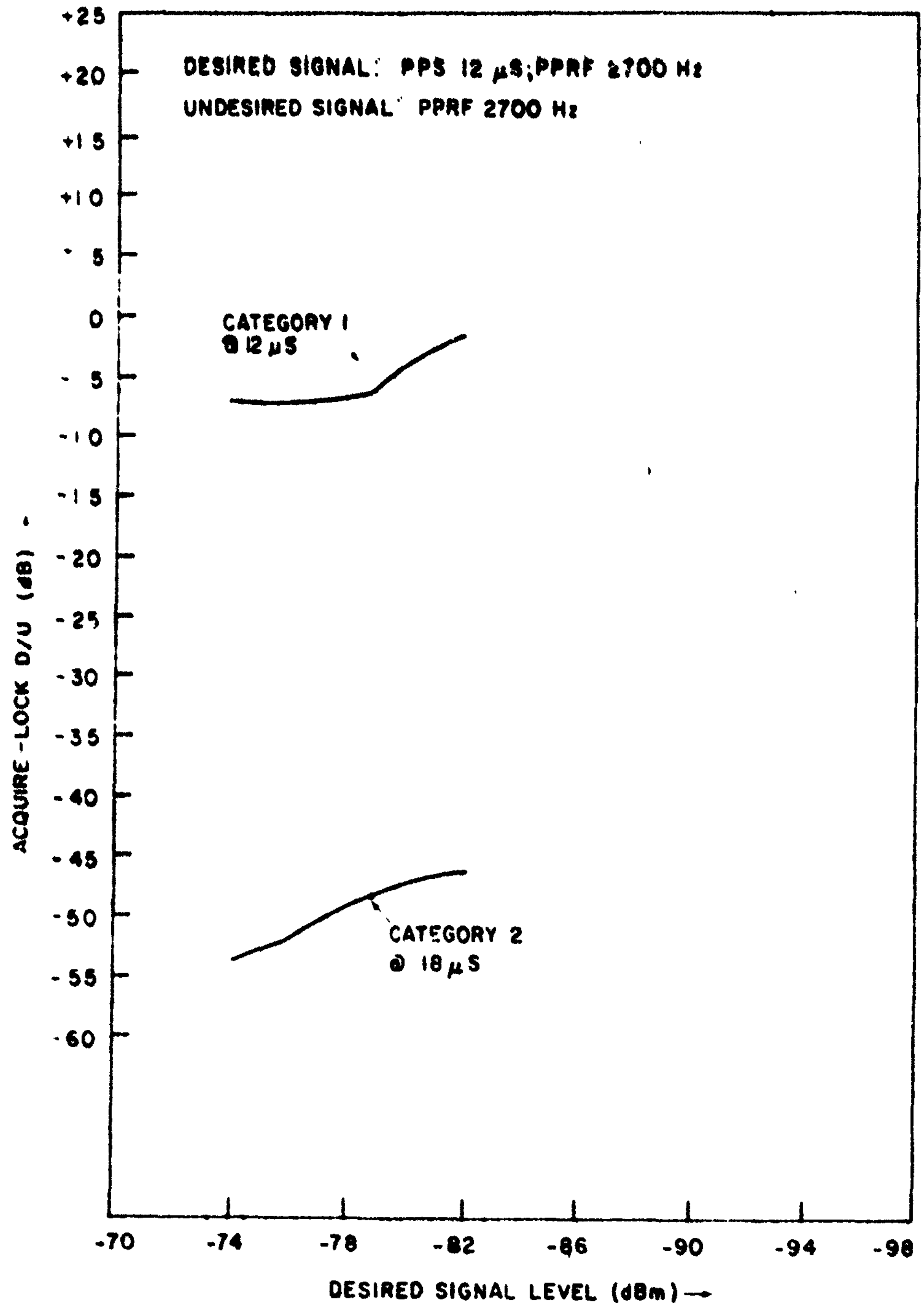


FIGURE 27. KING 705A EQUIPMENT.

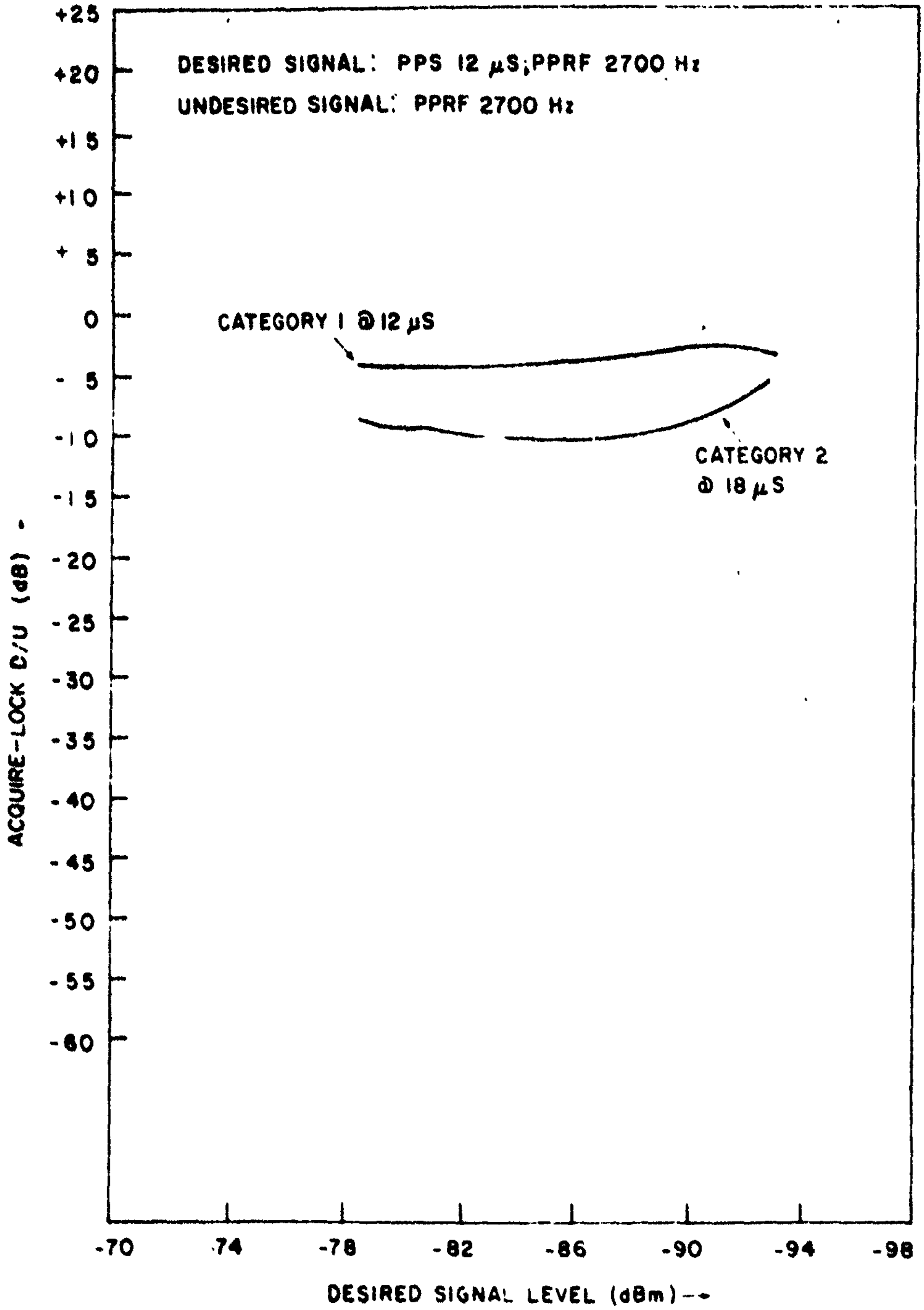


FIGURE 28. KING 7000 EQUIPMENT.

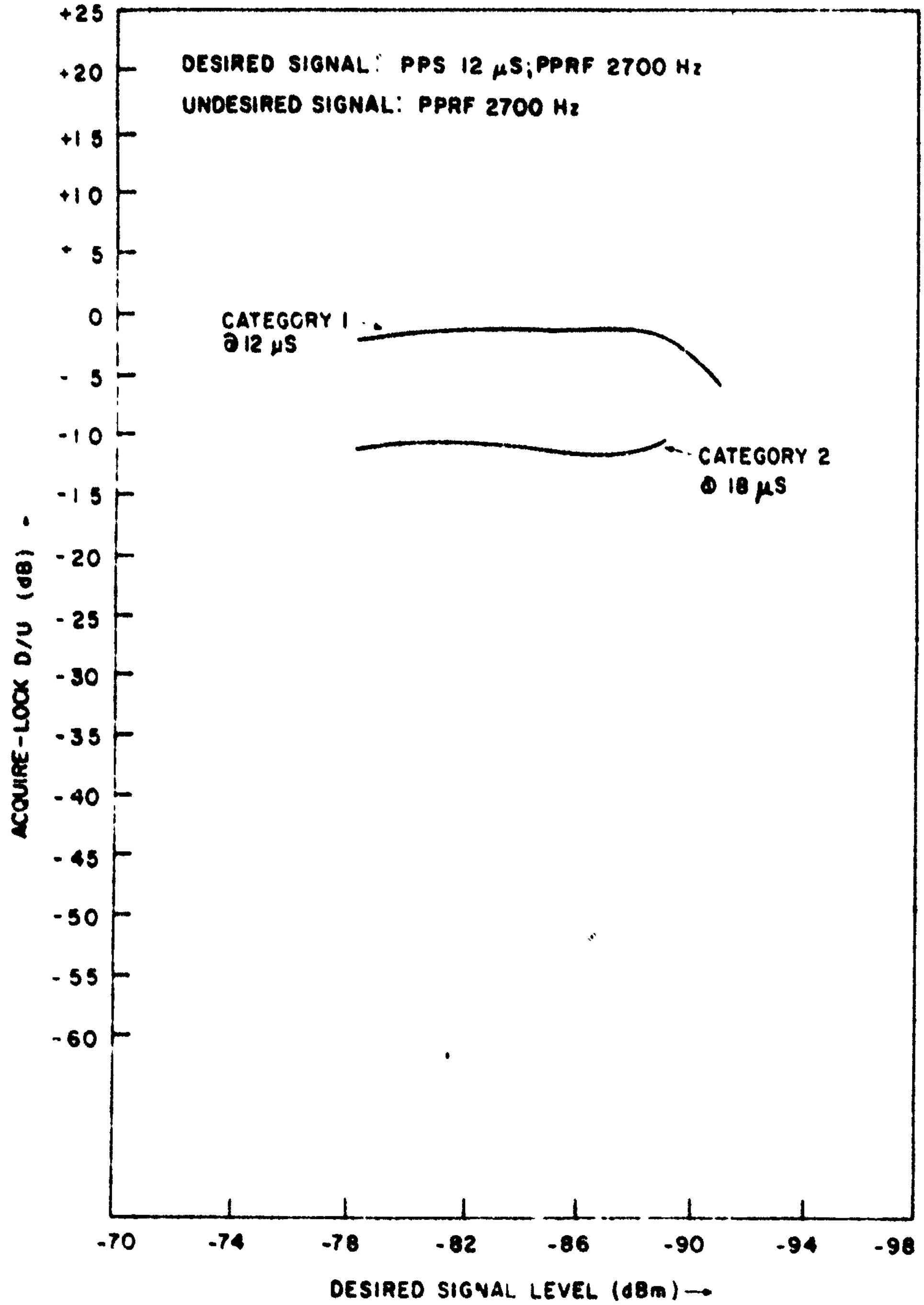


FIGURE 29. RCA AVA-70.

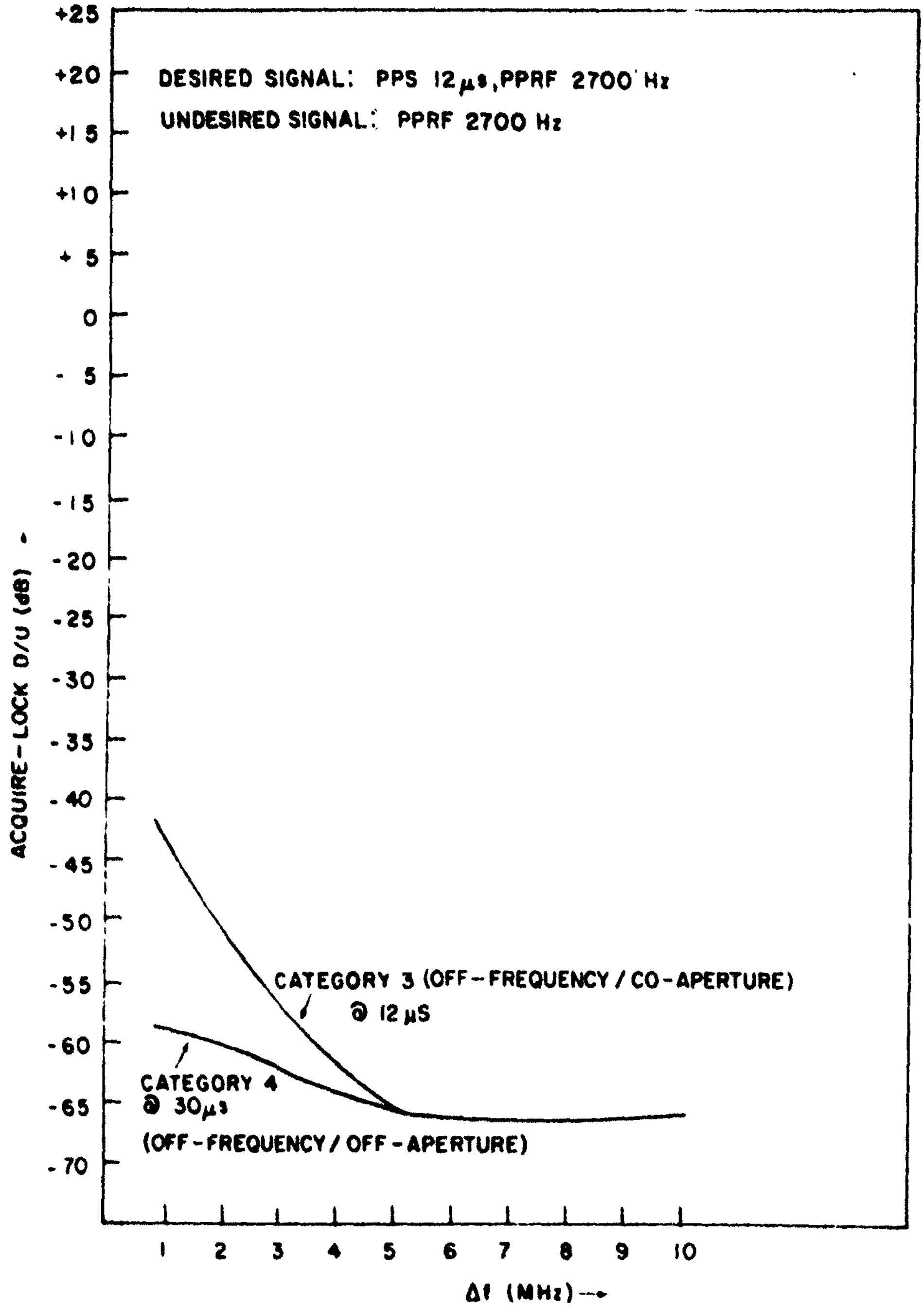


FIGURE 30. COLLINS 860 E-2 EQUIPMENT.

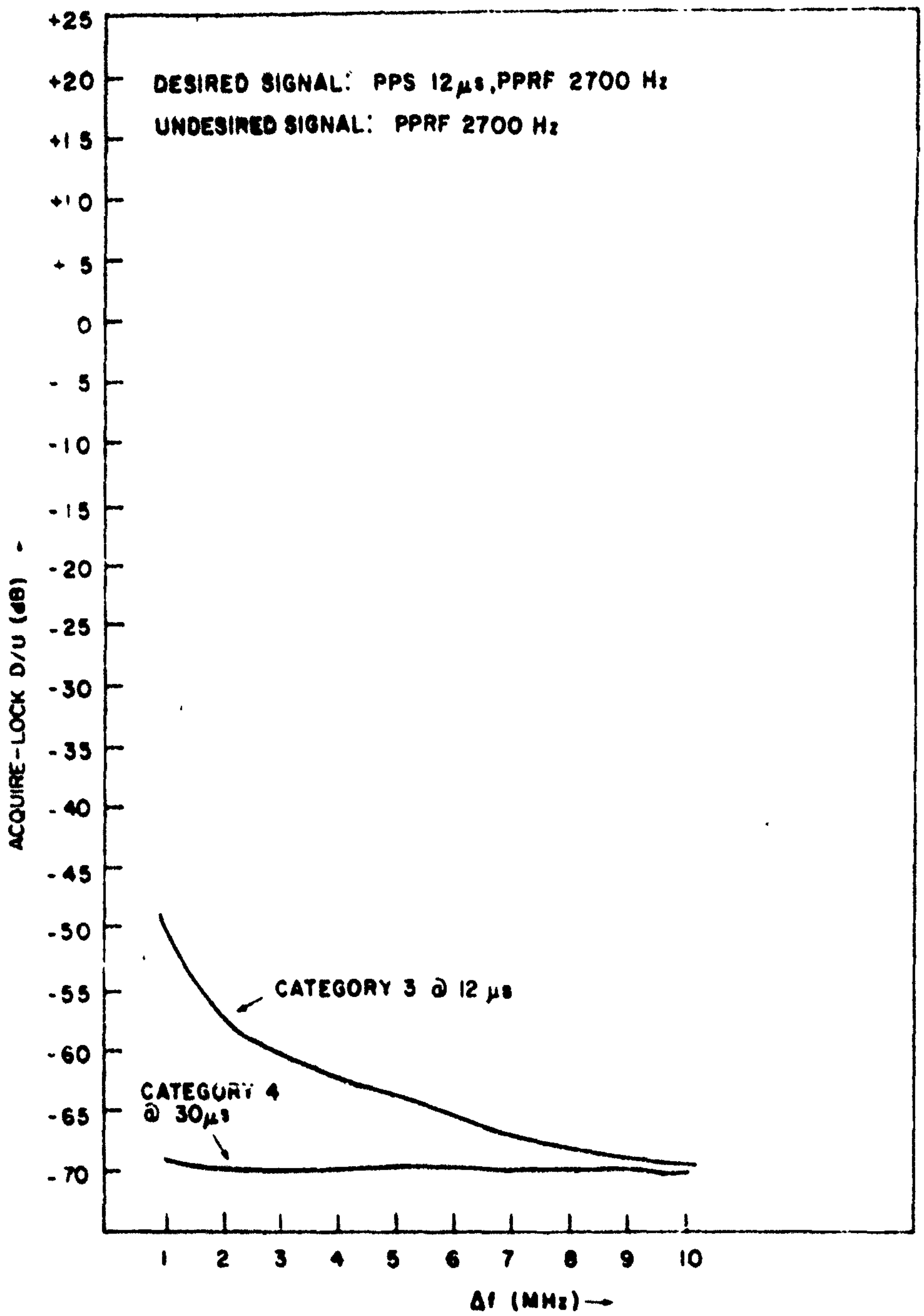


FIGURE 31. COLLINS 860 E-3 RECEIVER.

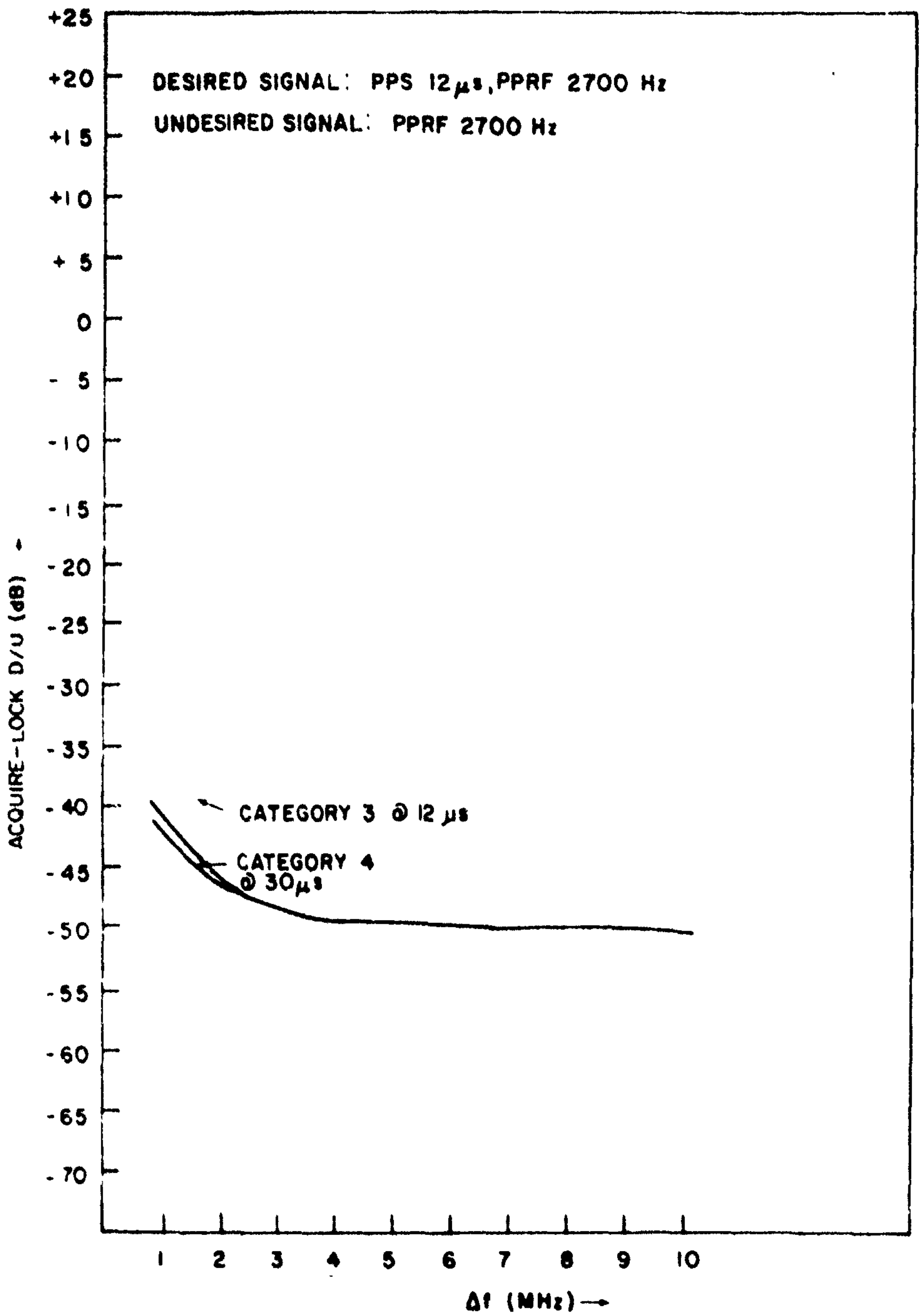


FIGURE 32. KN-60 EQUIPMENT.

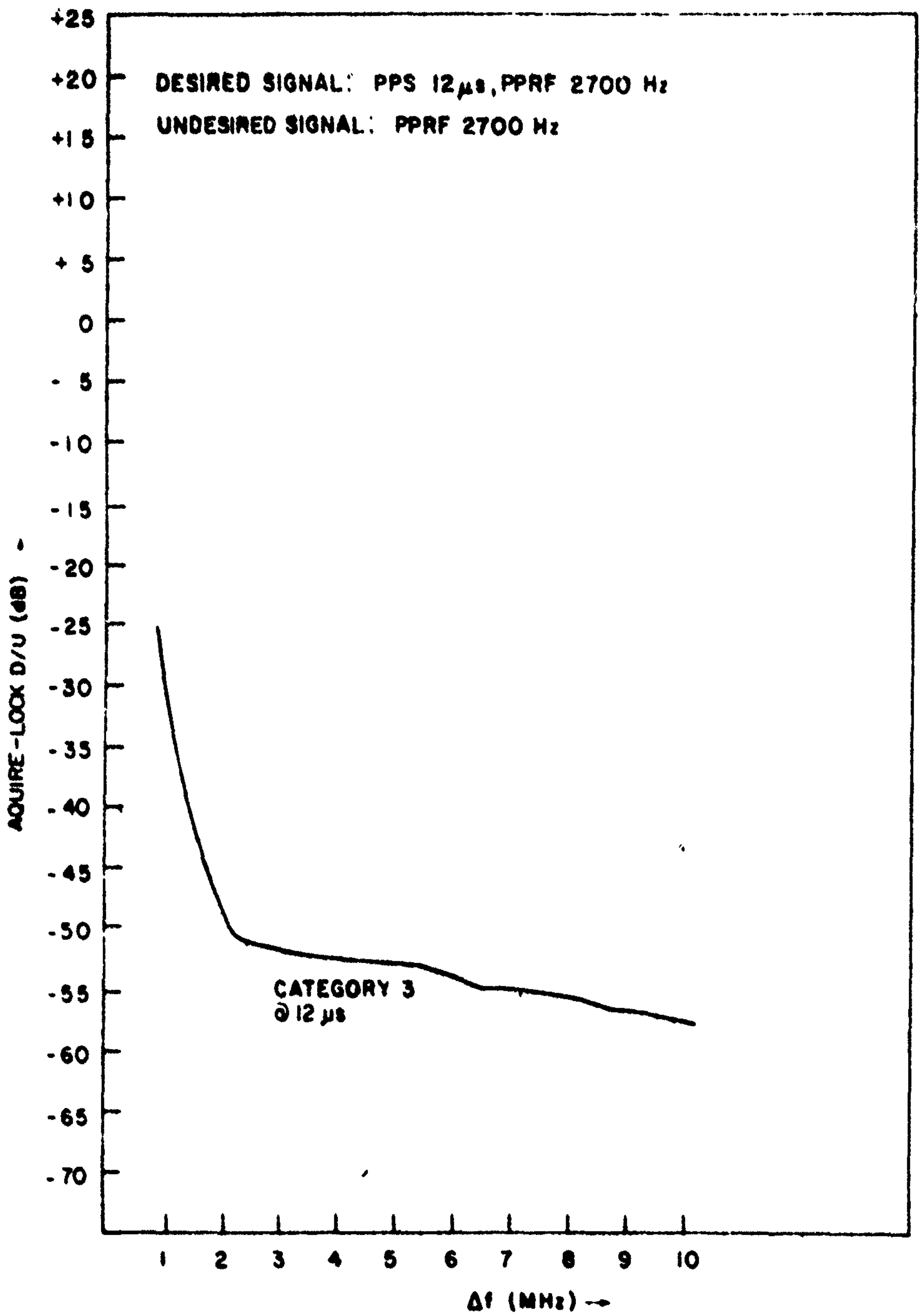


FIGURE 33. KN-65 EQUIPMENT.

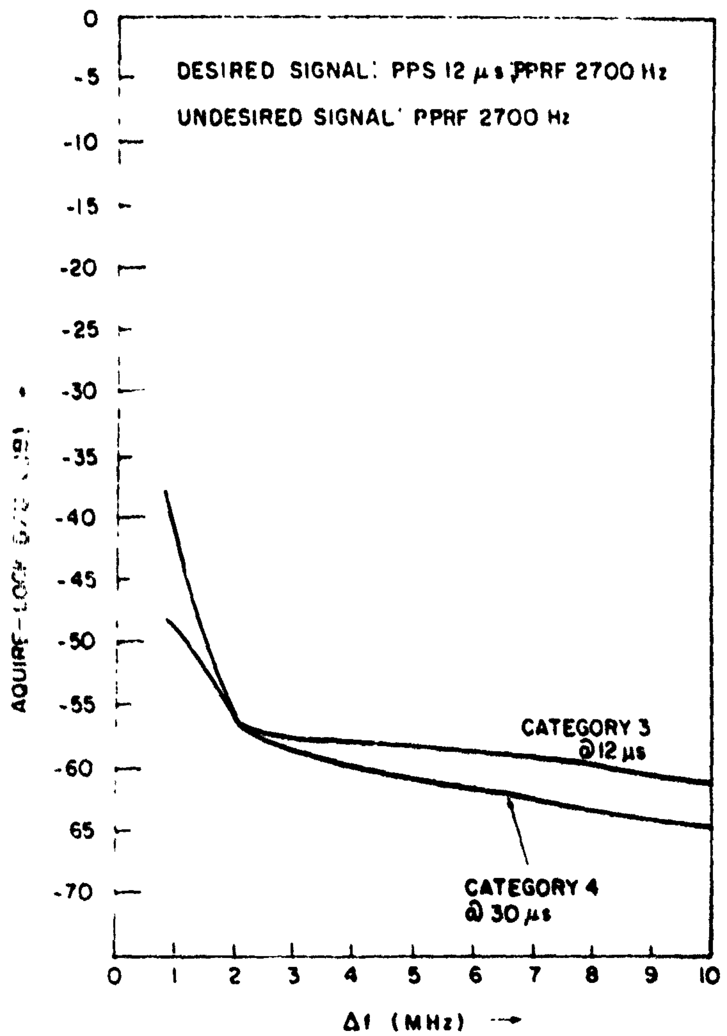


FIGURE 34. KING 705A EQUIPMENT.

TABLE 17

PDME INTERFERENCE TO CONVENTIONAL DME'S

Equipment Nomenclature	Category 1 Interference D/U (dB)	Category 2 Interference D/U (dB)	Category 3 Interference		Category 4 Interference	
			First Adjacent Channel D/U (dB)	Second Adjacent Channel D/U (dB)	First Adjacent Channel D/U (dB)	Second Adjacent Channel D/U (dB)
KN 60C	3	-2[b]	-40	-45	-42[b]	-46[b]
KN 65	2	-26	-25[b]	-30[b]	NA	NA
KDM 705A	7	-46.5	-38	-57	-48	-57
KING 7000	4	-6	-33	-52	-48	-61
COLLINS 860E-2	5	-55	-42	-50	-58	-60
COLLINS 860E-3	8[b]	-63	-49	-57	-70	-70
RCA AVA-70	6	-10	NA[a]	NA[a]	NA[a]	NA[a]

[a]Not available.

[b] Worst case values.

Category 1 Interference: The constraining D/U ratio from TABLE 17 for the range acquire-lock function is 8 dB. The pessimistic interference threshold[a] for the Ident function is 4 dB. Therefore, the worst-case D/U value for Category 1 interference is 8 dB. These D/U values can be linked with interacting transponder equipment separation distance using equipment ERP's, ITS propagation model, etc. The analysis results are listed in TABLE 18.

TABLE 18

PDME INTERFERENCE TO DME (CATEGORY 1): SEPARATION DISTANCE RESULTS

DME Service Volume Type	D/U (dB)	Total Separation Distance (nmi) Between Transponders	Interferer Distance From the Edge of Service Volume of the Desired Equipment (nmi)
High[a]	4 @ Ident	150	20
	8 @ range lock	170	40
Low	4 @ Ident	(b)	(b)
	8 @ range lock	48	8
Terminal	4 @ Ident	(b)	(b)
	8 @ range lock	31	6

[a]See TABLE 11 footnote.

[b]At low & terminal altitudes, no cochannel interference is possible because of antenna patterns, etc.

Category 2 Interference: The large variation in rejection levels from TABLE 17 for Category 2 interference is mainly due to differences in performance characteristics of the decoder circuits in different equipment.

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[a]See Intra-System PDME Interaction; Category 1 interference.

The worst performing decoder rejection is 5 dB. The overall interference threshold selected to protect against Category 2 interference depends on the chosen criteria. The criteria for selecting a threshold may include: (a) protecting all or some equipment based on NAFEC data; or (b) protecting equipment based on performance standards described in References 2 and 3.

From safety of life considerations, all avionics equipment should be protected. It implies that worst-case D/U ratio (3 dB) will be selected as an interference threshold and it will be a pessimistic criterion. It may be noted that selecting the D/U ratio based on worst performing decoder equipment may strain the channel assignment model to some extent.

Category 3 and Category 4 Interference: The analysis results for Categories 3 and 4 (TABLE 17) were obtained from FIGURES 30 to 35. This data was adjusted to account for the differences in spectra roll-off between the test signal and expected PDME signal format. Again, the variations in D/U values from equipment to equipment can be mainly attributed to different circuit designs used by the equipment manufacturers. The worst-case D/U values for Category 3 are -25 and -30 dB for first and second adjacent channels, respectively. The worst-case D/U value for Category 4 are -42 and -46 for first and second adjacent channels, respectively. This result primarily reflects the rejection characteristics of the front-end stages (i.e., RF and IF stages) of the DME receivers. As shown in TABLE 17, the interference thresholds for certain equipment are the same or nearly the same for Category 3 and 4 interference. Possibly in these equipments, the out-of-aperture interference impinging on the decoder circuit is comparable to the noise level, and therefore, no additional decoder rejection is contributed.

The overall results of the analysis of PDME interference to conventional DME's are summarized in TABLE 19.

PDME INTERFERENCE TO TACAN

The TACAN system provides the aircraft with azimuth, range, and identification information. Relevant characteristics of available TACAN avionics are listed in TABLE 20[a]. The adjacent-channel rejection characteristics of a representative TACAN front-end stages (no Ferris-Discriminator used in TACAN avionics receivers) for a potentially interfering PDME signal compared favorably with results already shown in FIGURE 21. Test data from NAFEC was appropriately modified in this case in order to account for the differences in spectral fall-off between the test signal and the PDME signal and also to include interference thresholds values at MDS/system and MDS/equipment.

TABLE 19

PDME INTERFERENCE TO DME, INTERFERENCE THRESHOLD VALUES

Interference Category	D/U (dB)	Comments
1	8	Degradation for acquire range lock
2	3	Based on worst performing decoder characteristics
3[a]	-34, -36	First and second adjacent channel.
4[a]	-51, -52	First and second adjacent channel.

[a]The D/U ratios for Category 3 and Category 4 interference from TABLE 17 have been adjusted by 9 dB and 6 dB for the first and second adjacent channels respectively. These adjustments are based on differences in spectral levels in the adjacent bands between the test signal spectrum (FIGURE 22) and theoretical spectrum (FIGURE 18).

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[a]The list covers a combined inventory of old and new equipment. The AN/ARC-52 represents the older equipment.

TABLE 20

CHARACTERISTICS OF SELECTED TACAN AVIONICS

Nomenclature	Components	PRF (Hz)	Transmitter Power kW)	Delay Time(µs)	Receiver Dynamic Range(dB)	Selectivity (kHz @ 3 dB)	Sensitivity (dBm)	Decoder Aperture (µs)
AN/ARN-84	Tube/Solid-state & IC	142-150 (search) 30 (track)	0.75-3.0	50 to 56	NA[a]	300	-90	12 ± 0.5 36 ± 0.5
AR/ARN-52(V)	Tube	150 30	3	NA	NA	330	-90	12 ± 0.5
AN/ARN-118	Solidstate Integrated Circuits	150 30	[illegible]	61.25-62.25 74.5-93.5	85	NA	NA	NA

[a]NA = Not available.

NAFEC data and plots of D/U (FIGURES 35 to 38 based on NAFEC data) were used to form a basis for estimating thresholds (TABLES 21 and 22) for PDME-to-TACAN interactions. These tables cover both azimuth and range functions and list the D/U values for various TACAN avionics receivers for each category of interference. The D/U ratio data for Category 1 interference was interpreted in terms of stronger (desired) signal acquire lock within the service volume as discussed previously. The analysis data indicates that except for Category 1 interference, the TACAN azimuth function is more susceptible to interference than the range function.

Category 1 Interference: The analysis (TABLES 21 and 22) shows that the pessimistic D/U values is 9 dB. However, D/U value of 8 dB was used in the results. It has been already stated that the interference threshold for the Ident function is 4 dB. Using the equipment ERP, established service volumes and loss predictions of the ITS progpagation model, an analysis of D/U ratios was made in terms of separation distance between the interacting couplet. TABLE 23 summarizes the separation distance results of this analysis and shows that the most constraining interference threshold value for Cataegory 1 interference is 8 dB.

Category 2 Interference: As in the case of DME, TACAN equipment exhibits a variation in decoder performance according to Category 2 data in TABLES 21 and 22. The interference thresholds were based on the criterion of worst performing decoder equipment data. The D/U ratio for the Category 2 interference is 6 dB and is listed in TABLE 24.

Category 3 and Category 4 Interference: In Category 3, TABLES 21 and 22, the pessimistic D/U values are -33 dB and -41 dB for the first and second adjacent channel, respectively. The adjusted D/U ratios are -42 dB, -47 dB for the first and second adjacent channels, respectively, accounting for differentials in the emission spectra levels. These D/U ratios for the adjacent channels are comparable to the expected values shown in the curve of FIGURE 21. In the case of Category 4 interference, the constraining D/U values are -42 dB and -47 dB because the interference suppressed by the front-

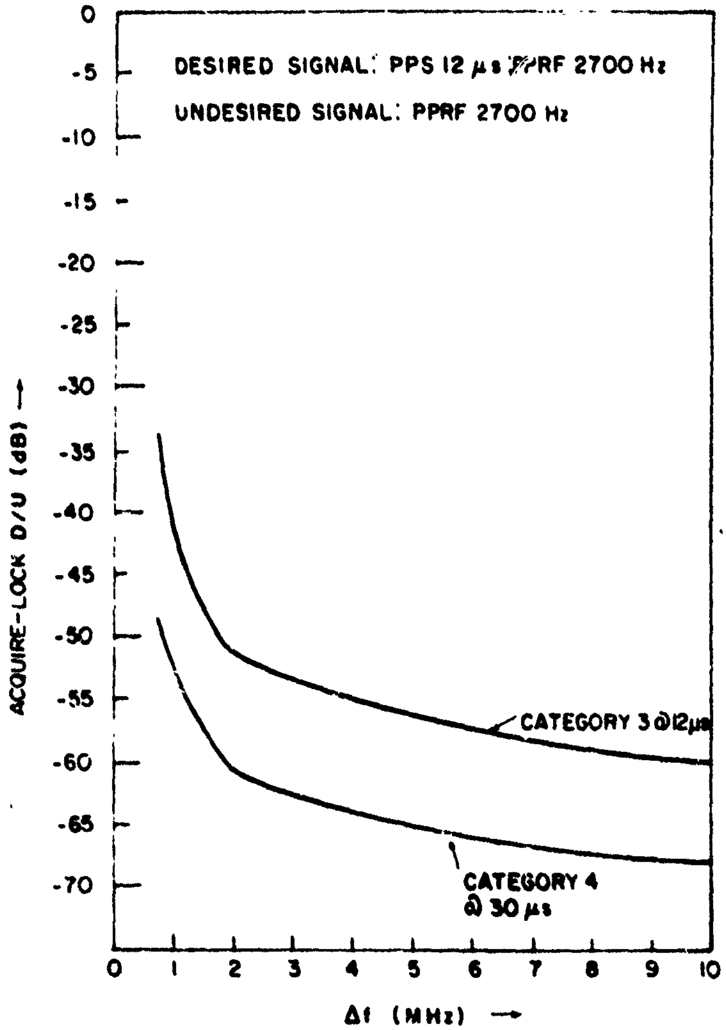

FIGURE 35. KING 7000 EQUIPMENT.

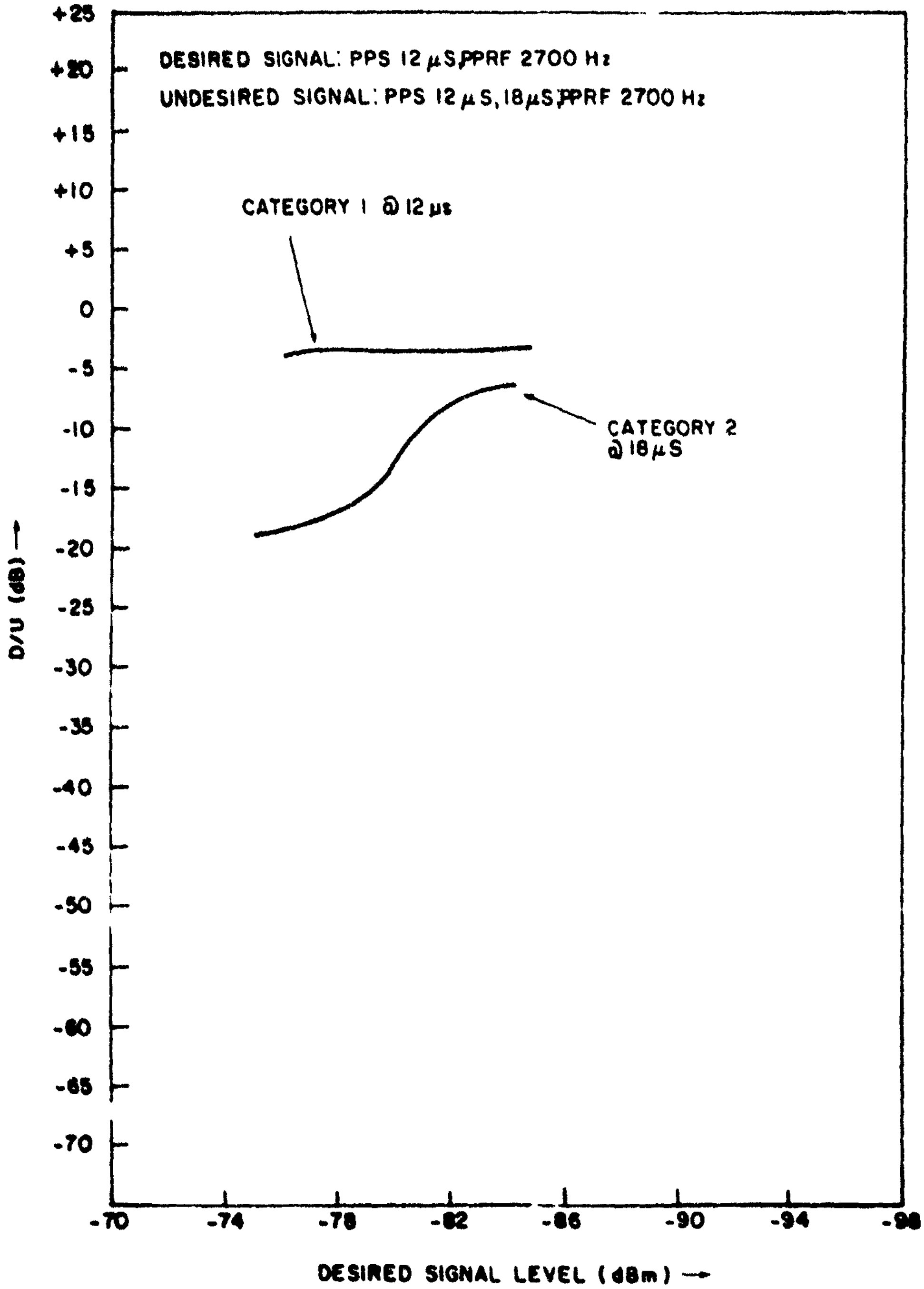

FIGURE 36. AN/ARN-52 EQUIPMENT.

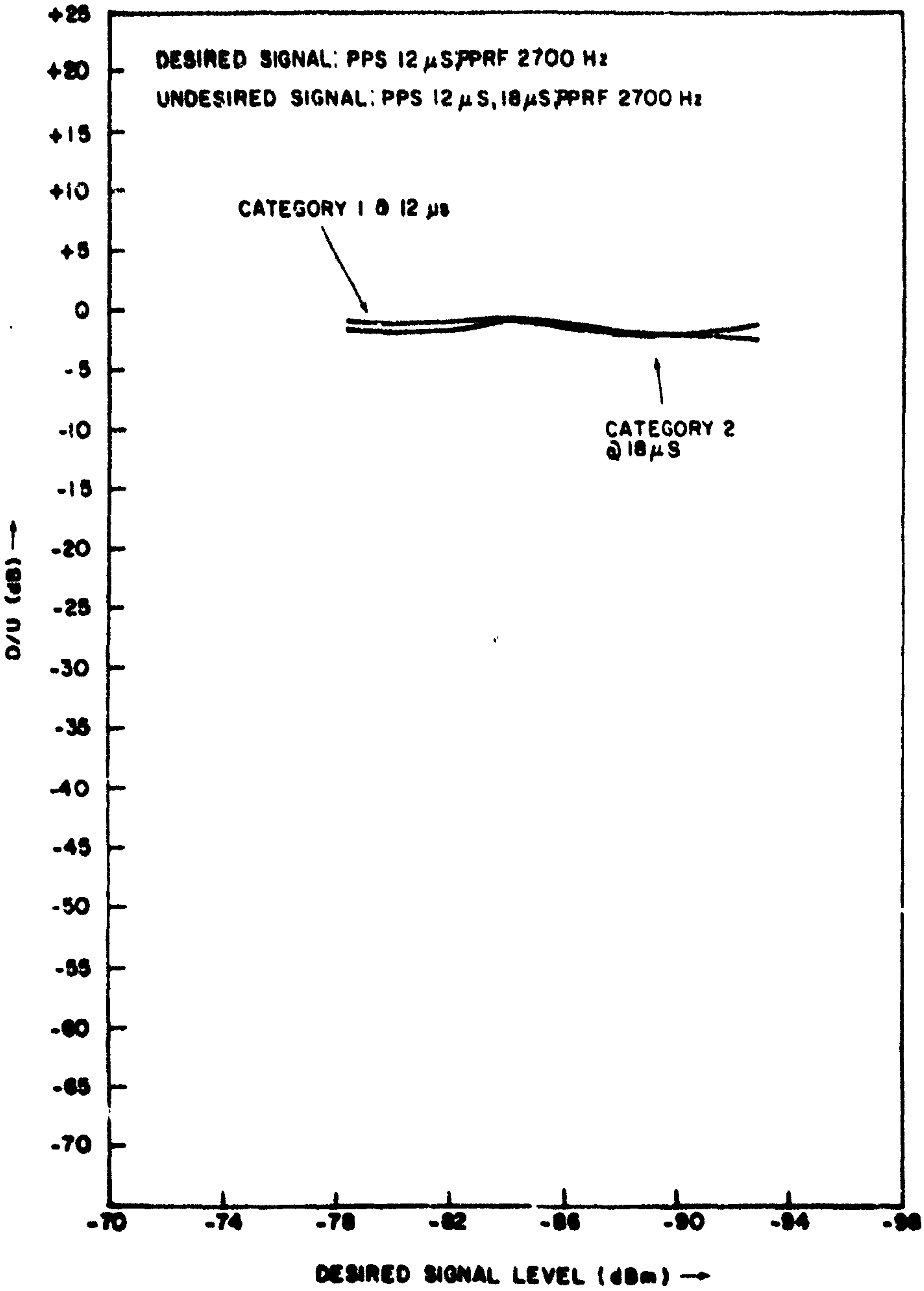

FIGURE 37. AN/ARN-84 EQUIPMENT.

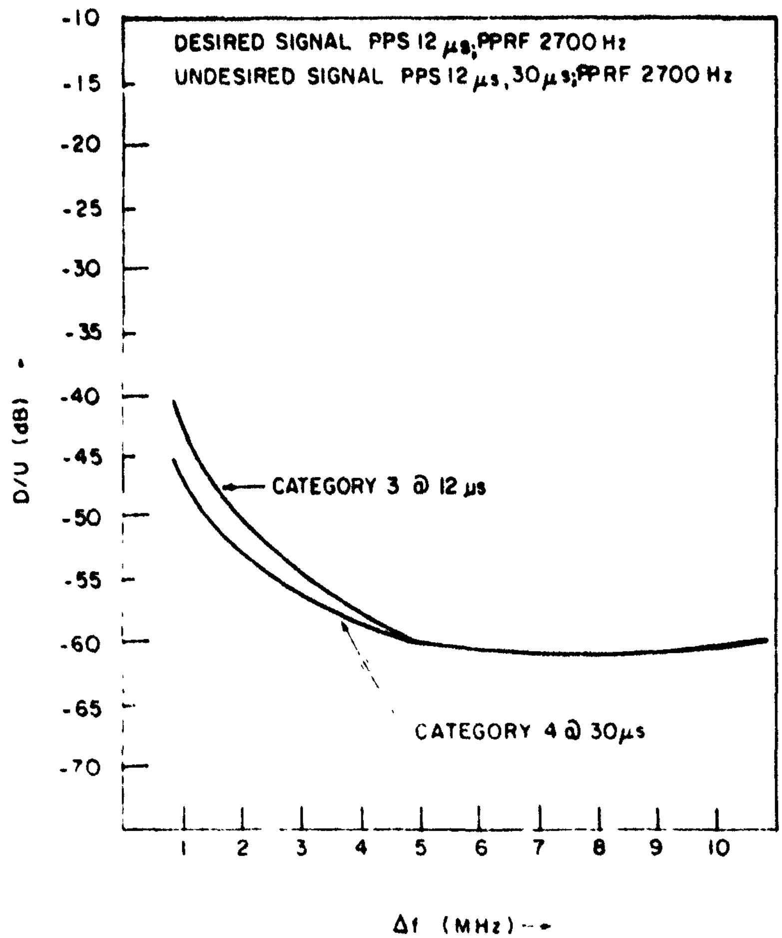

FIGURE 38. AN/ARN-52 EQUIPMENT.

TABLE 21

PDME INTERFERENCE TO TACANS: D/U RESULTS FOR AZIMUTH FUNCTION

Equipment Nomenclature	Category 1 Interference D/U (dB)	Category 2 Interference D/U (dB)	Category 3 Interference: First Adjacent Channel D/U (dB)	Category 3 Interference: Second Adjacent Channel D/U (dB)	Category 4 Interference: First Adjacent Channel D/U (dB)	Category 4 Interference: Second Adjacent Channel D/U (dB)
AN/ARN-52	+3	-7	-43	-51	-45	-53
AN/ARN-84	+1	-1.0[b]	-33[b]	-41[b]	-33[b]	-41

[a]NA = Not available.
[b]Worst case

TABLE 22

PDME INTERFERENCE TO TACANS: D/U RESULTS FOR RANGE FUNCTION

Equipment Nomenclature	Category 1 Interference D/U (dB)	Category 2 Interference D/U (dB)	Category 3 Interference: First Adjacent Channel D/U (dB)	Category 3 Interference: Second Adjacent Channel D/U (dB)	Category 4 Interference: First Adjacent Channel D/U (dB)	Category 4 Interference: Second Adjacent Channel D/U (dB)
AN/ARN-52	+4.5	-58.5	-41	-54	-54	-55
AN/ARN-84	+9[a]	-46.5	-56	-59	-69	-72

[a]Worst case value

TABLE 23

PDME INTERFERENCE TO TACAN (CATEGORY 1): SEPARATION DISTANCE RESULTS

TACAN Service Volume	D/U (dB)	Total Separation Distance (nmi) Between Transponders	Interferer Distance From the Edge of Service Volume of Desired Signal (nmi)
High	+4 @ Ident	149	19
	+8 @ acquire range lock	153	23
[a]Low	+4 @ Ident	-	-
	+8 @ acquire range lock	-	-
[a]Terminal	+4 @ Ident	-	-
	+8 @ acquire range lock	-	-

[a]Separation distance does not apply because of high differential in ERP values for the low and terminal service volumes.

end stages is of little significance in most of the subsequent decoder circuits. The adjusted D/U ratios are noted in TABLE 24.

The overall results of the interference analysis of PDME interference to TACAN receivers are summarized in TABLE 24.

TABLE 24

PDME INTERFERENCE TO TACAN;
PESSIMISTIC INTERFERENCE THRESHOLDS

Interference Category	D/U (dB)	Comments
1	8	Degradation based on acquire lock
2	6	Criterion of worst performing decoder equipment
3	-42, -47	First and second adjacent channels.
4	-42, -47	First and second adjacent channels.

TACAN/DME INTERFRENCE TO PDME

The intra-system PDME interactions, discussed earlier, showed that the interference thresholds depend primarily on the characteristics of the key circuits in the victim receiver. The same situation applies in the case of TACAN/DME interference to the PDME receiver. However, the impact of TACAN/DME interference on the PDME receiver may be less severe for adjacent-channel interference because the potentially interfering TACAN/DME pulses have a slower rise time (narrower spectrum as compared to potentially interfering PDME pulses). As a result, the separation distance requirement for the interfering couplet will be different in the present case.

Category 1 and Category 2 Interference: The interference thresholds for the PDME receiver for Category 1 interference have already been established in

the previous intra-system PDME section. These ratios hold for the present case also. The interpretation of these ratios in terms of separation distance between interacting equipment was made using ERP's, the ITS propagation model, etc. The results of the analysis are listed in TABLE 25 in terms of the separation distance requirement. The pessimistic D/U ratio is 6 dB for Category 1 interference. In the case of Category 2 interference, the pessimistic interference threshold will be a-50 dB, based on the victim PDME receiver decoder characteristics discussed previously.

TABLE 25

TACAN/DME INTERFERENCE TO PDME (CATEGORY 1): SEPARATION DISTANCE RESULTS

Case	D/U (dB)	Between Transponders	Service Volume of Desired Signal
TACAN to PDME	3 (break lock)	202	182
	6 (acquire lock)	204	184
	+4 (Ident)	203	183
DME (1 kW) to PDME	3 (break lock)	188	168
	6 (acquire lock)	190	170
	+4 (Ident)	187	167

Category 3 and Category 4 Interference: The adjacent-channel rejection in the IF stages was determined by convolving representative emission spectra of TACAN/DME with the precision mode and enroute mode selectivity curves of PDME receivers. The results are given in FIGURES 39 and 40. The enroute mode OFR was approximately derived.

As shown in these figures, the maximum rejection from front-end stages is below 10 dB at 1 MHz and 18 dB at 2 MHz, which is small compared to the dual mode Ferris Discriminator rejection level. Therefore, the interference threshold level for precision mode Category 3 interference is primarily set by the dual mode Ferris-Discriminator characteristics. The pessimistic D/U ratio for Category 3 (precision mode) interference was considered as -60 dB and -75

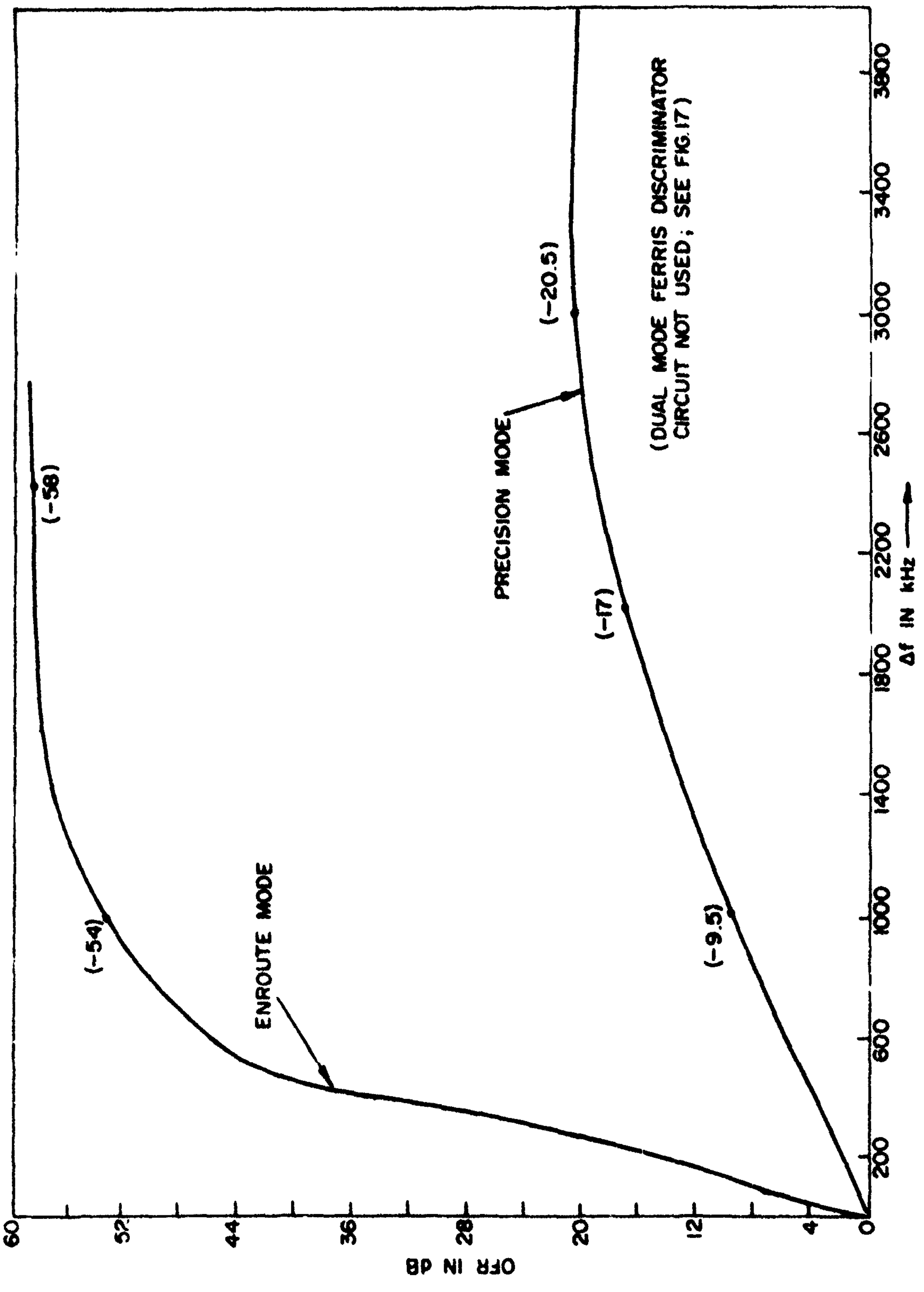

FIGURE 39. TACAN VERSUS PDME (PRECISION AND ENROUTE MODE); OFR PLOT. (BASED ON TACAN THEORETICAL EMISSION SPECTRUM AND PDME MEASURED SELECTIVITY CURVE.)

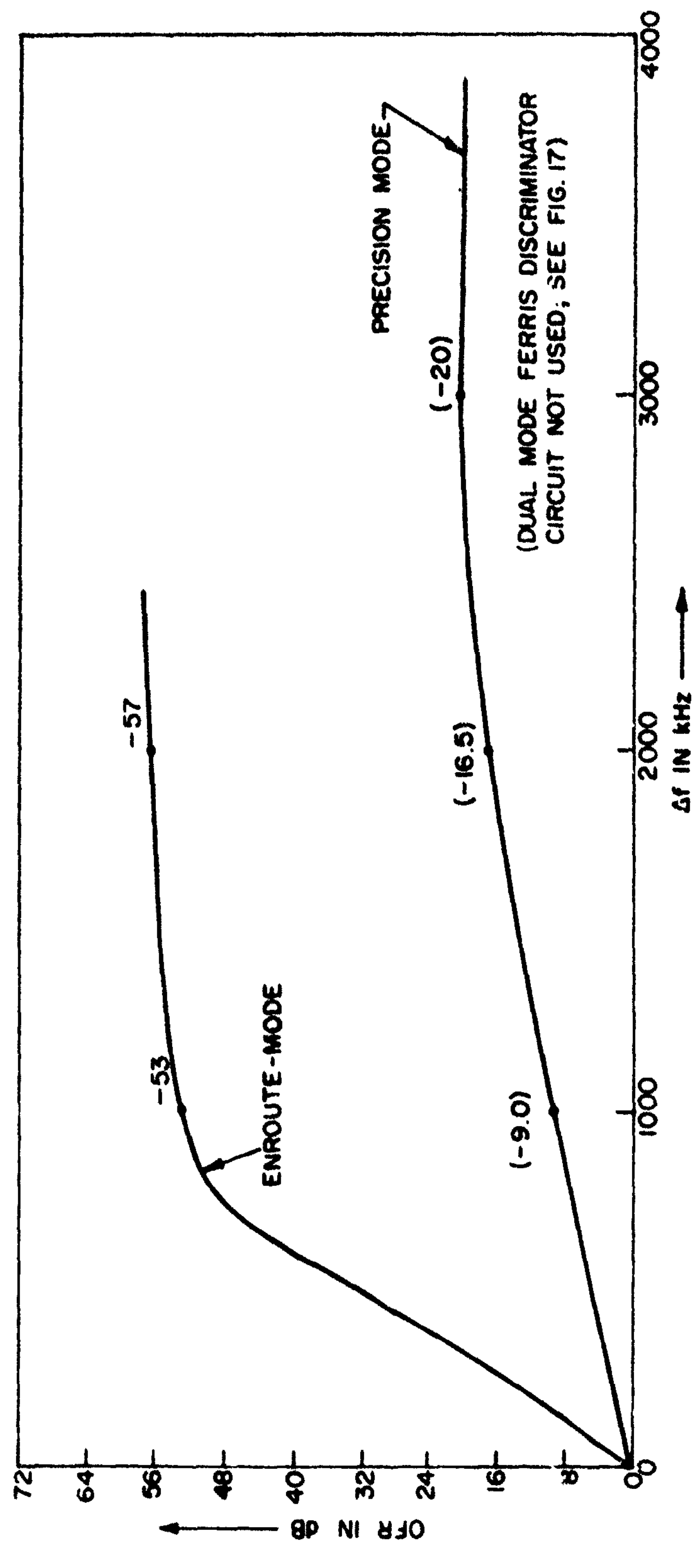

FIGURE 40. CONVENTIONAL DME VERSUS PDME (PRECISION AND ENROUTE MODES); FDR PLOT. (BASED ON DME THEORETICAL EMISSION SPECTRUM AND PDME MEASURED SELECTIVITY CURVE.)

dB (combined front-end and dual mode Ferris-Discriminator characteristics) for the first and second adjacent channels, respectively. The D/U ratios for the enroute mode Category 3 are -47 dB and -51 dB for the first two adjacent channels.

The interference thresholds (pessimistic values) for the Category 4 interference are based on the second adjacent-band data of Category 3 interference. Therefore, D/U ratios for Category 4 will be -75 dB for the precision mode and -51 dB for the enroute mode for the adjacent channels. The results of the analysis are listed in TABLE 26.

TABLE 26

TACAN/DME INTERFERENCE TO PDME: PESSIMISTIC INTERFERENCE TRESHOLDS

Interference Category	D/U (dB)	Comments
1	6	Acquire lock criterion
2	-50	Pessimistic value
3	-60,-75(Precision mode) -47,-51(Enroute mode)	Pessimistic values for the first and second adjacent channels
4	-75,-75(Precision mode) -51,-51(Enroute mode)	Pessimistic values for the first and second adjacent channels

INTRA-AND INTER-SYSTEM TACAN/DME INTERACTIONS

There are four different types of interactions to be considered between the TACAN and DME equipment. The interference thresholds for these interactions for each category of interference were determined using equipment protection rules, Ident function degradation levels, minimum performance

standards of equipment, and circuit characteristics. The details of the analysis are described below:

Intra-System TACAN Interactions

According to the U.S. National Aviation Standards[8] on VORTAC systems, a signal from a undesired cochannel component will be at least 8 dB below the signal from the desired component. In other words, maintaining a D/U ratio of +8 dB for Category 1 interference is mandatory in the frequency assignment process. This ratio is also supported by the consideration that for preserving the azimuth information (which has modulation swings of about ± 4 dB), the quiescent levels of the interacting equipment should be separated by 8 dB. Separation distance analysis was made for maintaining a D/U ratio of 8 dB between the interacting TACAN equipment. The results are summarized in TABLE 27 for the three types of service volume. The standards also state that the signal from an undesired first adjacent-channel component will not exceed the desired signal by more than +42 dB. Furthermore, signals other than cochannel or first adjacent channels shall not exceed +50 dB of the desired signal at any point above the radio horizon and within the operational service volume of the desired component. Thus, it is required that for Category 3 interference, D/U ratios of -42 and -50 dB have to be maintained for the first and second adjacent channels, respectively.

The decoder circuits in TACAN avionics receivers have a variation in performance. However, based on the channel/frequency allocation in the 960-1215 MHz band, the Category 2 and Category 4 cases do not apply in the present case of interaction. Assuming that the decoder circuit offers no additional rejection to low level interfering signals, the pessimistic D/U ratio for Category 4 interference is -50 dB. The summary of D/U ratios for intra-system TACAN interference is listed in TABLE 28.

[8]Advir · Circular on U.S. National Aviation Standards for the VORTAC System, FAA, .. of Transportation, June 10, 1976.

TABLE 27

INTRA-SYSTEM TACAN INTERACTIONS (CATEGORY 1): SEPARATION DISTANCE[a] RESULTS

Service Volume Mode	D/U (dB)	Total Separation Distance (nmi) Between Transponders	Interferer from the Edge of Service Volume of Desired Signal (nmi)
High	+8	375	245
Low	+8	175	135
Terminal	+8	120	95

[a]Power allowance for monitor is not included here.

TABLE 28

INTRA-SYSTEM TACAN INTERACTIONS: INTERFERENCE THRESHOLDS

Interference Category	Pessimistic D/U(dB)	Comments
1	+8	Based on VORTAC protection rules.
2	-	Not applicable.
3	-42,-50	First and second adjacent channels, respectively, based on protection rules.
4	-	Not applicable.

Intra-DMF Interactions

The TACAN transponder equipment in comparison to DME transponder equipment operate at a higher ERP and use spectrum filters in the beacon transmitter to comply with ICAO Annex 10 and adjacent-channel spectral constraints. In addition, the azimuth function in TACAN equipment is more vulnerable to interference than is either the range or Ident function. Since

these features apply to TACAN equipment only, the interference threshold values derived in the preceding section do not apply to the DME's. The details of the analysis procedure for intra-system DME (1 kW and 100 watt equipment) interference thresholds are given in APPENDIX D. The key points are repeated here.

The cochannel (Category 1) interference threshold is based on the potential degradation of the range function, for which a D/U ratio of 8 dB is required. This ratio will be valid to both the 1-kW and 100-watt DME units. The desired separation distances for the type of DME service volumes were analyzed and the results are listed in TABLE 29. In this case also, the Category 2 and Category 4 interference does not exist for both types of DME units because of channel/frequency allocation procedures in the 960-1215 MHz band.

TABLE 29

INTRASYSTEM DME INTERACTIONS (CATEGORY 1): SEPARATION DISTANCE RESULTS

Service Volume Mode	D/U (dB)	Total Separation Distance (nmi) Between Transponders	Interferer Distance From the Edge of the Service Volume of Desired Signal (nmi)
High	8	376	346
Low	8	177	137
Terminal	8	127	102

The adjacent-channel interference thresholds were determined by convolving a theoretical emission spectrum with a general selectivity curve of DME receivers (see APPENDIX D). Cosine-squared waveforms were examined to check compliance with ICAO Annex 10 spectral constraints. The off-frequency rejection (OFR) values for such a waveform, (e.g., a 3.5-microsecond pulse width and a 2.06-microsecond rise and fall time) were -37.4 dB and -55.5 dB for the first and second adjacent channels, respectively (TABLE D-1).

In terms of Category 3 interference, the D/U ratios for the 1-kW DME unit are -39.4 and -47.5 dB, respectively for the first and second adjacent channel. For the 100-watt DME unit, the D/U values will be -29.4 dB and -37.5 dB for the first two adjacent channels. The results of intra-DME interference thresholds are listed in TABLE 30.

TABLE 30

INTRASYSTEM DME INTERACTIONS:
INTERFERENCE THRESHOLDS

Interference Category	Pessimistic D/U (dB)	Comments
1	8 [1-kW & 100-W DME]	Based on degradation in the range acquire-lock function.
2		Not applicable.
3	-39.4,-47.5 [1-kW DME] -29.4,37.5 [100-W DME]	First and second adjacent channels; based on general analysis in APPENDIX D.
4		Not applicable.

TACAN Interference to DME

The approach in determining the interference threshold was the same as in the preceding sections. For on-channel interference (Category 1), the range function is most susceptible to degradation. Therefore, the constraining D/U ratio for Category 1 interference is 8 dB. The separation distances necessary to maintain that D/U ratio are listed in TABLE 31 for all types of service volumes. The adjacent-channel interference analysis was based on the convolution of a TACAN emission spectrum and a DME receiver selectivity curve using the FDR CAL program (APPENDIX E). The interference thresholds for Category 3 interference are -46 dB and -54 dB. The results of this analysis are summarized in TABLE 32.

TABLE 31

TACAN INTERFERENCE TO DME (CATEGORY 1): SEPARATION DISTANCE RESULTS

Service Volume Mode	D/U (dB)	Total Separation Distance (nmi) Between Transponders	Interferer Distance From the Edge of the Service Volume of Desired Signal (nmi)
High	8	376	246
Low	8	193	153
Terminal	8	138	113

TABLE 32

TACAN INTERFERENCE TO DME: INTERFERENCE THRESHOLDS

Interference Category	Pessimistic D/U (dB)	Comments
1	8	Based on degradation in the range acquire-lock function.
2	-	Not applicable.
3	-46, -54	First and second adjacent channels; based on general characteristics of the interacting equipment.
4	-	Not applicable.

DME Interference to TACAN Equipment

In this case, it is the range acquire-lock function which determines the interference threshold for the cochannel interference. Therefore, the constraining D/U ratio for Category 1 interference was 8 dB. Separation distances were determined for the above D/U ratio between the interacting equipment and these are listed in TABLE 33 for all types of service volumes. The interference thresholds for Category 3 interference were based on emission and selectivity characteristics of the interacting equipment. The pessimistic

D/U ratios for this case were -39 dB and -48 (1-kW DME) and -29 dB, -38 dB (100-watt DME) for the first and second adjacent channels. The results of the analysis are given in TABLE 34.

TABLE 33

DME INTERFERENCE TO TACAN (CATEGORY 1): SEPARATION DISTANCE RESULTS[a]

Service Volume Mode	D/U (dB)	Total Separation Distance (nmi) Between Transponders	Interferer Distance From the Edge of the Service Volume of Desired Signal (nmi)
High	8	373	243
Low	8	158	118
Terminal	8	105	80

[a]Distance separations are based on transmitter powers given in TABLE 12.

TABLE 34

DME INTERFERENCE TO TACAN

Interference Category	Pessimistic D/U (dB)	Comments
1	8 [1-kW & 100-W DME]	Based on acquire range lock.
2	-	Not applicable.
3	-39,-48 [1-kW DME] -29,-38 [100-W DME]	First and second adjacent channels; based on general characteristics of the interacting equipment.
4	-	Not applicable.

This section addressed the interference threshold analysis for the L-Band PDME, DME and TACAN equipment for the four categories of interference. Section 3 of this report summarizes the overall results of this analysis along

with explanations and interpretations. These results provide an important input for an initial exercising of the channel assignment.

SECTION 3

RESULTS/SUMMARIZATIONS/COMMENTS

MLS/C-Band Equipment Interactions

This portion of analysis determined the interference thresholds for all combinations of interactions between the MLS configurations/functions for the cases of cochannel and adjacent-channel interference. The focal point in this analysis was the transformation of MLS error budgets for different MLS configurations/functions into the interference thresholds (D/U ratios) at the system level. The main results of the analysis and the interpretations are given below.

Adjacent-Band Analysis Results:

The first step in the analysis was to determine the D/U ratios at the function level (TABLE 3). These D/U values characterize the receiver performance when subjected to interference from the undesired MLS guidance functions. The function level D/U ratios were transformed to system level D/U ratios (TABLE 6) using the adjustment factors (TABLE 5). The adjustment factors were determined graphically with DPSK channel as the reference base. The constraining D/U ratio selected on this reference base ensures protection from interference for all combinations of interactions between the MLS configurations/functions.

On a system basis, the Preamble/Data channel was found to be more susceptible to interference among all the cases (TABLE 7). The constraining interaction is an SB signal from an undesired Full Capability MLS Configuration versus a PD channel of the victim equipment. The most constraining D/U ratio is -21 dB (TABLE 7) for the first adjacent channel. The rejection factor data of TABLE 2 was used for determining D/U ratios in the other adjacent-band channels. The constraining D/U vaues are -23 dB, -26 dB and -28 dB for the second, third and fourth adjacent channels, respectively. This data is plotted in FIGURE 41.

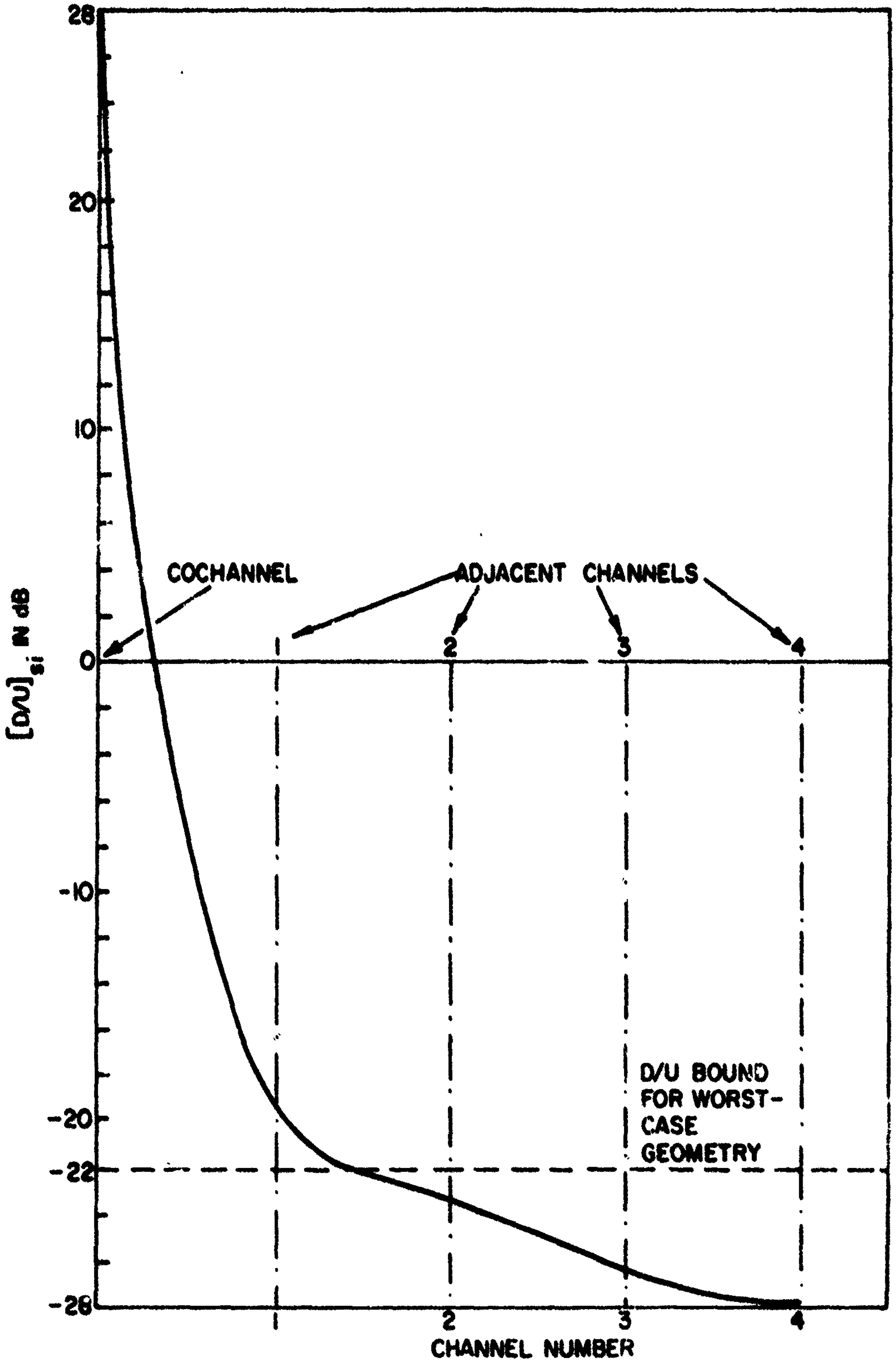

FIGURE 41. CHANNEL NUMBERS VERSUS $[D/U]_{si}$ FOR MLS/C-BAND EQUIPMENT.

For adjacent-channel interference, the ITS predictions - (Reference 4) were used to determine the worse-case D/U location (within and outside the service volume) based on separation distance, aircraft altitude, antenna patterns, etc. It was determined that the worst-case geometry occurs when airport facilities are separated by 21 miles and with the victim aircraft at an altitude of 2100 feet. This situation is illustrated in FIGURE 42. The D/U ratio for this geometry is 22 dB (FIGURE 43).

The D/U results of the preceding analysis on adjacent-channel interference and worst-case geometry of MLS equipment location are summarized in FIGURE 41. These results indicate that to accommodate the situation of worst-case MLS equipment location (FIGURE 42) and to preclude interference from the constraining Intra-MLS Configuration interactions (e.g., from an undesired Full Capacity equipment vs the desired Minimum Capability equipment), the undesired MLS signal should be assigned at least the second adjacent channel. The frequency separation based on this criteria should, therefore, preclude adjacent-channel interference for all possible interactions between MLS Configuration/function and locations of the MLS equipment.

The results of the adjacent-channel interference analysis hold for the values of rejection factors (TABLE 2), ΔEIRP (TABLE 4) and CMN error budget (TABLE 1) given in this section. Any changes in these values will modify the constraining D/U ratios. However, any new D/U values could be readily determined by the procedures described in this report.

It should be noted that these adjacent-channel results do not make allowance for the monitor power tolerances between the desired and undesired facilities. Dependent upon what this value is for the final MLS system configurations, the number of adjacent channels removed in the frequency assignment criteria can be greater than that indicated herein.

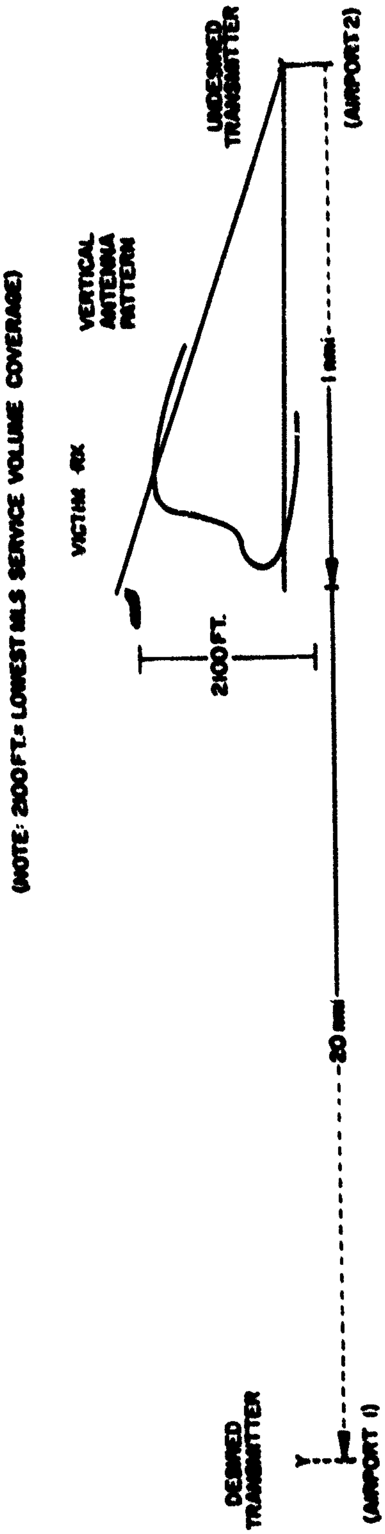

FIGURE 42. WORST-CASE GEOMETRY FOR ADJACENT-CHANNEL INTERFERENCE.

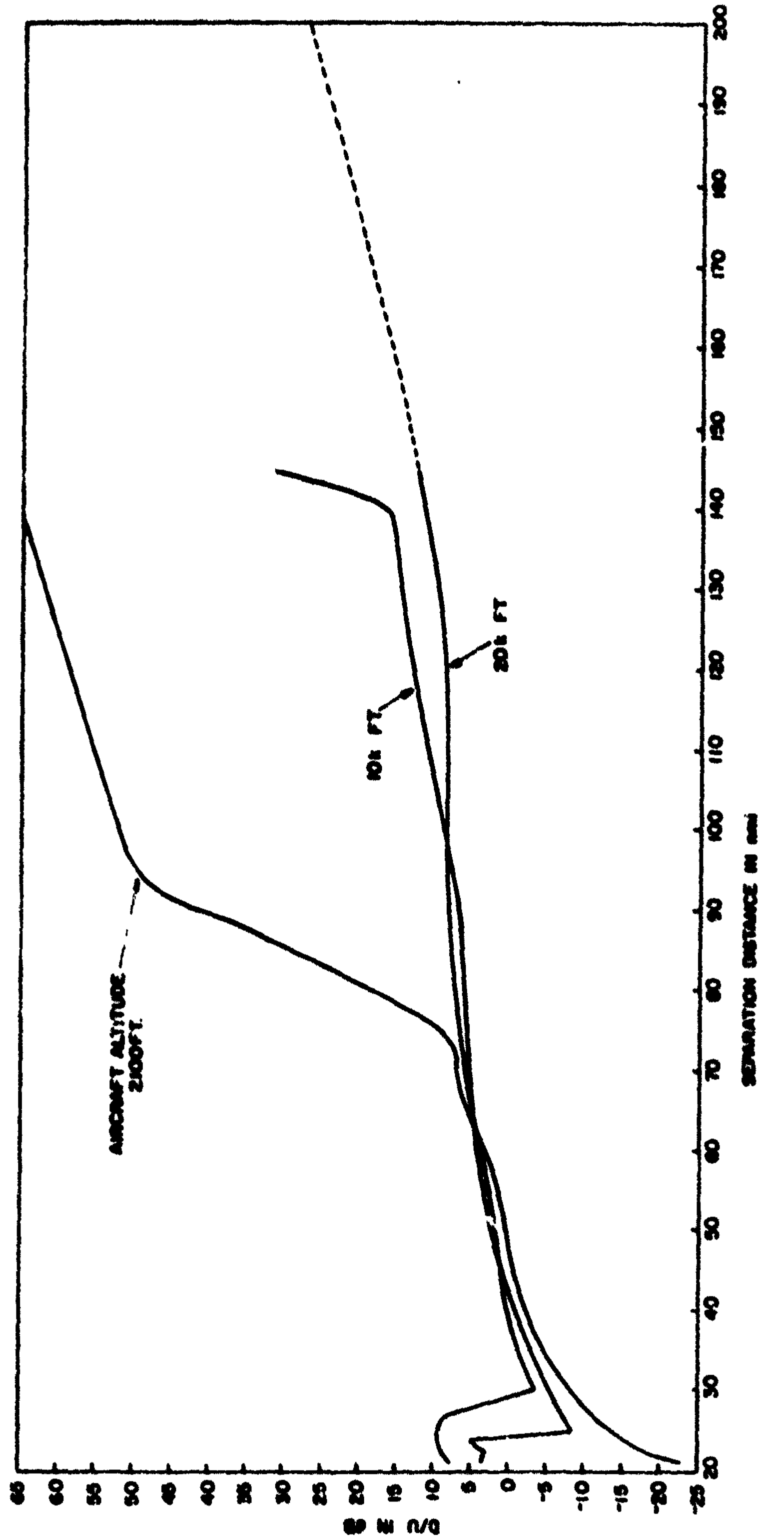

FIGURE 43. D/U VERSUS FACILITY SEPARATION DISTANCE (AFTER THE ITS PROPAGATION MODEL).

Cochannel Analysis Results:

The cochannel analysis was based on distortion caused in the scan beam signal due to multipath effect (i.e., interference being a nearly coincident signal and replica of the desired signal). The interference thresholds (TABLE 10) were determined at the system level. The most constraining D/U value at the system level is 24 dB and it occurs for the case of undesired signal from a Minimum Capability MLS equipment interacting with the desired Full Capability equipment. The separation distance requirements, to preclude interference for the most constraining case, are based on the path loss predictions of the ITS propagation model and the results are listed below:

MLS Receiver Altitude (Kilo feet)	Separation Distance (nmi) estimated Between Desired & Undesired MLS Ground Equipment
2.1	82
10	142
20	193

The cochannel interference analysis performed in Section 2 is based on the most constraining interference situation. Therefore, the analytic procedure provides pessimistic values of D/U ratios and the associated separation distances.

L-Band Equipment (PDME, TACAN, DME) Interactions

The overall interference threshold results of the L-Band equipment analysis are summarized in TABLE 35. The D/U results are the same for many cases of interactions. This is because the pessimistic D/U ratios are listed and most of these are derived on the basis of characteristics of the key receiver circuits and also using minimum allowable performance standards pertaining to this equipment. The separation distance requirements are different for each of these interactions because different parameters such as transmitter power, service volume and antenna gain/pattern were used in the ITS propagation model (Reference 4) for each case. The results of the

TABLE 35

CONSTRAINING INTERFERENCE THRESHOLDS FOR THE L-BAND AVIONICS EQUIPMENT

Interfering Equipment	Categories[a]	Victim Equipment D/U Thresholds TACAN (dB)	DME (dB)	PDME[b] (dB)
TACAN	1	8	8	8
	2	-	-	-50
	3[c]	-42, -50	-46, -54	-60, -75
				-47, -51
	4	-	-	-75, -75
				-51, -51
DME (1 kW)	1	8	8	8
	2	-	-	-50
	3	-39, -48	-39, -48	-60, -75
				-47, -51
	4	-	-	-75, -75
				-51, -51
DME (100 watt unit)	1	8	8	8
	2	-	-	-50
	3	-29, -38	-29, -38	-37, -41
	4	-	-	-75, -75
				-41, -41
PDME	1	8	8	8
	2	6	3	-50
	3	-25, -34	-25, -34	-60, -75
				-37, -49
	4	-34, -34	-34, -34	-75, -75
				-49, -49

[a]Category 1 - Cofrequency/coaperture interference.
Category 2 - Cofrequency/out-of-aperture interference.
Category 3 - Adjacent-channel/coaperature interference.
Category 4 - Adjacent-channel/out-of-aperature interference.

[b]In Categories 3 and 4 for PDME, the two levels of D/U ratio refer to the precision and enroute modes.

[c]In Categories 3 and 4, the two levels of D/U ratio pertain to the first and second adjacent channels.

Not applicable cases are denoted blank.

separation distance analysis are presented in the tables of Section 2. The comments summarizing the basis of the analysis results are described below.

PDME Avionics Equipment

The D/U ratio of 6 dB derived for Category 1 interference indicates the dynamic range of the AGC circuit of the prototype PDME equipment. However, in the channel assignment process, a D/U of +8 dB should be considered so that this ratio conforms with the standard accepted value for other types of L-Band equipment. The Category 2 interference D/U ratio (-50 dB) is based on the decoder characteristics of the PDME equipment. It is a pessimistic value and invariant of the type of interferer.

The two sets of D/U ratios for Category 3 interference pertain to the precision mode and enroute modes of operation. The precision mode D/U values (-60 dB, -75 dB) primarily reflect the rejection characteristics of the dual mode Ferris Discriminator circuit. The enroute mode D/U ratios (-37,-41) was derived from the OFR plot based on the narrow-band IF selectivity curve in the enroute mode. The implementation of the enroute mode (narrow-band) selectivity in the PDME circuits is still under development by the Bendix Co. The interference thresholds for the Category 4 interference are the pessimistic values because no circuit data was available.

DME Avionics Equipment

The D/U ratio (8 dB) for Category 1 interference comes from the equipment protection rules which are eventually linked with the typical characteristics of the IF amplifier /AGC circuit. The case of Category 2 and Category 4 interference does not apply for the intra-system DME as well as inter-system TACAN/DME interactions because of current channel/frequency allocation factors in the 960-1215 MHz frequency band.

The adjacent-band interference (Category 3) D/U ratios were derived by convolving a theoretical emission spectrum (cosine squared wave form in time

domain) with a general selectivity curve for the avionics receiver. The derived D/U ratios for the 1-kW and 100-watt DME equipment comply with the ICAO Annex 10 constraints.(APPENDIX D) The minimum allowable performance standards dictate that the undesired signal power should not exceed - 7 dBW in a 0.5 MHz bandwidth with 0.8 MHz offset from its center frequency. It therefore, follows that the 100-watt DME has an adavantage of 10 dB in the D/U ratio over the 1-kW DME. The additional cushion of 10 dB can be useful either in modifying the existing DME waveforms (permitting sharper rise & fall times and better accuracy) or in reducing the stress on the channel assignment process. It should be noted that the frequency assignment procedures are predicated on meeting the ICAO Annex 10 constraints. The present assignments assume that no margin of 10 dB in the D/U ratio exists. This implies that should the basic DME waveform be changed in the future for whatever reasons, the deletion of the 10 dB margin will negate any future frequency re-assignments.

The D/U ratios for the PDME interference (Category 1 and Category 2) were based on processed NAFEC data. The Category 2 threshold value (-3 dB) accomodates the characteristics of the worst performing avionics equipment in terms of rejection offered by the decoder circuit because of safety of life considerations. The D/U ratios for Category 3 interference were based on the minimum allowable performance standards (i.e. - 7 dBW interference level in a 0.5 MHz bandwidth at 0.8 MHz frequency offset) rather than the NAFEC data. The Category 4 D/U ratios are again the pessimistic values.

TACAN Avionics Equipment

The derivation of D/U ratios for the TACAN equipment is comparable to that of the DME equipment. The D/U ratios for the intra-system TACAN interactions were extracted from the VORTAC standards (Reference 8). The Category 1 D/U ratio of 8 dB comes from the prescribed protection rules. The Category 2 and Category 4 interference do not apply for the cases of intra-system TACAN and inter-system TACAN/DME interactions because of present channel/frequency allocation fatotors. The Category 3 interference thresholds

were based on the minimum allowable performance standards mentioned earlier for both the 1-kW and 100-watt interfering DME equipment.

In the case of interference from PDME, the D/U ratios for Category 1 and Category 2 interference were derived from the modified NAFEC data. The Category 2 D/U ratio (6 dB) was chosen to accomodate the worst performing equipment (in terms of rejection offered by the decoder circuit) from safety of life considerations. The D/U ratios for the adjacent-band interference are chosen on the basis of allowable performance standards for Category 3 interference and pessimistic values for the Category 4 interference.

The interference analysis of L-Band equipment encompasses several types of interactions and the D/U ratios were derived using several sources of information. The proposed D/U ratios are conservative and provide a useful input for an initial exercising of the channel assignment model.

APPENDIX A

MICROWAVE LANDING SYSTEM

GENERAL

The Microwave Landing System[a] (MLS) is comprised of range-guidance and angle-guidance equipment. The angle-guidance equipment uses the Time Reference Scanning Beam (TRSB) technique which provides precision azimuth, elevation, and flare guidance to aircraft approaching, landing at, and departing from an airport. The angle-guidance is provided in a service volume as shown in FIGURE A-1. The system operates in the 5-5.25 GHz band with 200 channels, each 300 kHz wide, designated for the angle-guidance operation. TABLE A-1 lists the available angle receiver specifications. The range-guidance equipment, called PDME, is presently planned for the L-Band frequencies (960-1215 MHz). The functional characteristics and concepts of the MLS are described below:

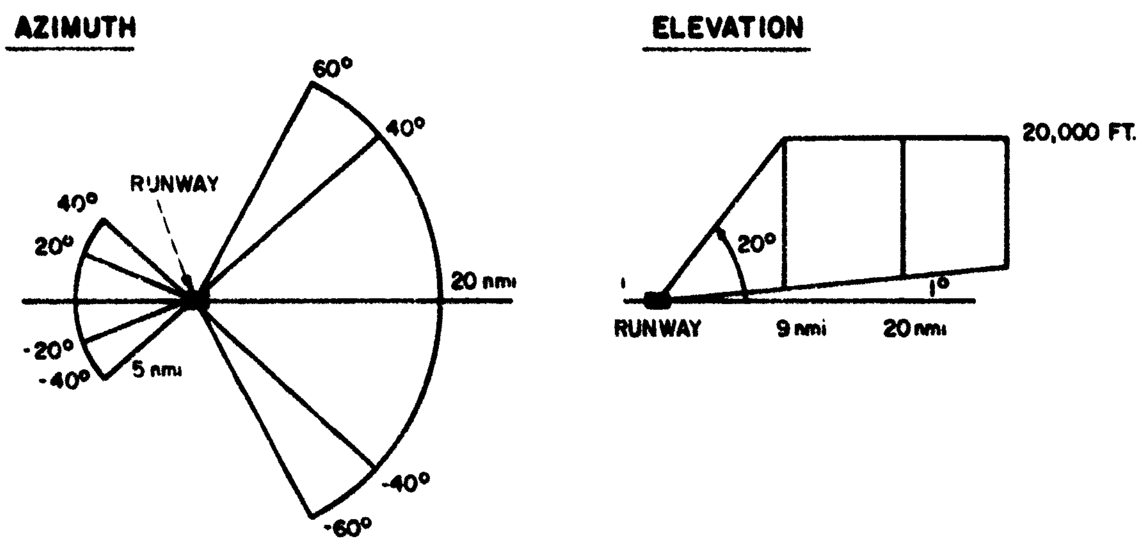

FIGURE A-1. MLS SERVICE VOLUME.

[a]ICAO Submission by FAA, contains detailed description of Microwave Landing System.

TABLE A-1

MLS ANGLE RECEIVER[a] SPECIFICATIONS

Characteristic	Description
Input Frequency Range	5031.00 to 5090.70 MHz
Number of Channels	200
Channel Spacing	300 kHz
Frequency Stability	$\pm$ 50 kHz max.
(Long Term Stability 1 yr.)	$(1P.10^{5})$
Channel Bandwidth (-3 dB)	$\pm$ 75 kHz min.
Adjacent-Channel Rejection (min)	-60 dB min.
Spurious and Image Rejection (min)	
Below 4750	75 dB
4750 to 5000 (Image)	70 dB
5000 to 5130 (All channels except Adjacent)	75 dB
5130 to 5350	70 dB
Above 5350	75 dB
Type of Channel Selection	2 out of 5
Type of Localizer and Glide Slope Selection	serial binary
Max. Signal Input (Mixer Burnout)	
CW	+ 20 dBm
Pulse	+ 40 dBm

[a]Bendix Avionics Division Maintenance Manual.

Angle Guidance

The TRSB signal format is based on the TO-FRO scanning beam technique, in which narrow fan beams scan through the service volume in alternate directions. The beams are scanned at high speed and consist of a single, unmodulated, continuous ratio frequency transmission. The scanning speed is uniform, starting from one extermity of the coverage sector and moving to the other and then beack again to the starting point, thus producing a TO-FRO scan as shown in FIGURE A-2 for azimuth. The azimuth beam scans first counterclockwise and then clockwise, as viewed from above. The elevation beam scans first down and then up. In every scanning cycle, two pulses are received by the aircraft. The time interval between the TO and FRO pulses is proportional to the angular position of the aircraft with respect to the

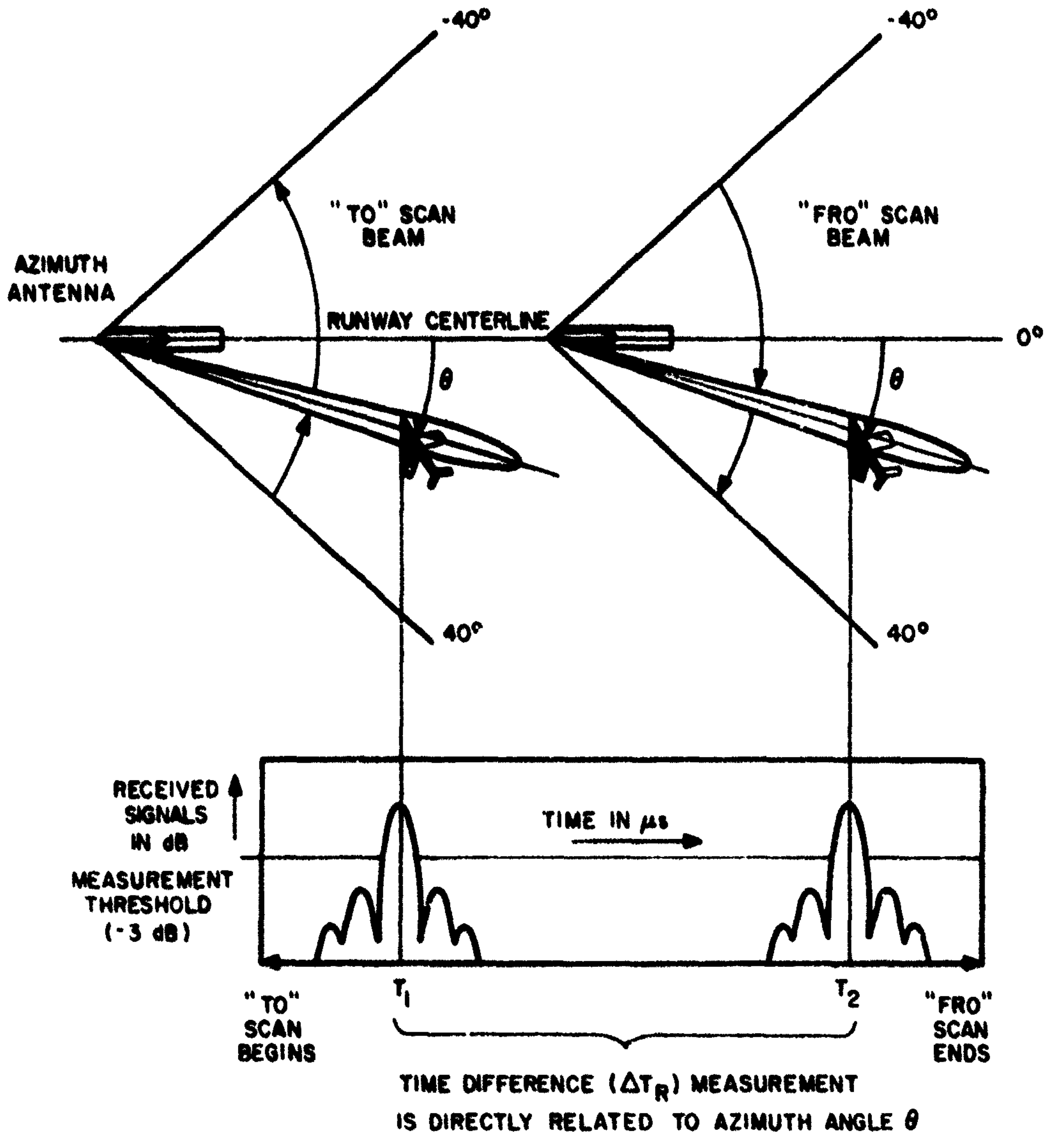

FIGURE A-2. TIME DIFFERENCE MEASUREMENT.

runway. An important feature of the time-reference-encoded scanning beam system is the high data rate, 13.5 Hz for azimuth and 40.5 Hz for elevation. These data rates make it possible to design simple airborne processors that can minimize any multipath effects on guidance signals.

All angle and data functions are time-muliplexed on the assigned radio frequency so that a single receiver-processor channel may process all data. Since each function is an independent entity in the time-muliplexed sequence, the receiver may decode functions in any sequence. This is accomplished by providing each function with a preamble that, upon reception, sets the receiver for the function which follows. The function identification preamble is radiated on a sector antenna covering the function guidance guidance volume. The scanning fan beam and the sector transmission are illustrated in FIGURE A-3.

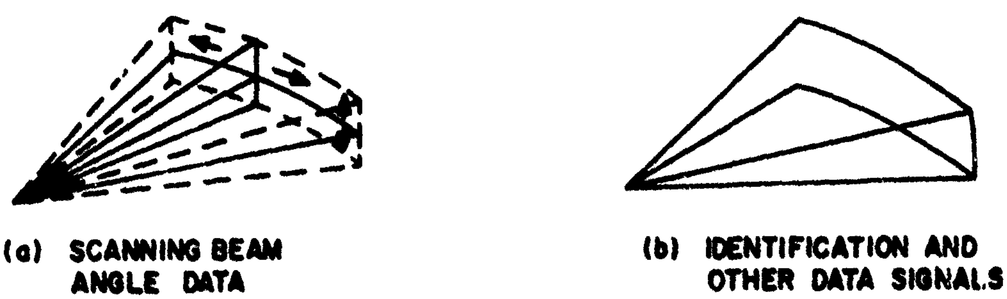

FIGURE A-3. REPRESENTATION OF THE ANGLE AND PREAMBLE RADIATION CHARACTERISTICS.

All angular information is essentially linear throughout the volume of coverage. Precision azimuth angle guidance is provided to at least ±40°, or a narrower sector if desired. For any installation, and particularly where proportional coverage is reduced for reasons of economy, left-right guidance information may be provided over a wider sector. Precision elevation angle

guidance, referenced to a standard reference point, is provided from 1° to 20° in elevation, over the same sector that provides azimuth angle guidance. Precision missed-approach azimuth angle guidance, referenced to runway centerline, is provided to at least ±20°.

The proposed standard signal format contains a time slot for the addition of 360° azimuth and missed-approach elevation guidance to meet potential future requiremnts, and the design concept is sufficiently flexible to permit the implementation of alternate means for providing a 360° azimuth capability for particular national requirements. Such an alternative could be implemented at C-Band with either electronic or mechanically scanned antennas and could be made compatible with standard receivers by a simple processor augmentation.

RANGE DETERMINATION

Range information is obtained in suitable equipped aircraft in the conventional manner by measuring the round trip time between the transmission of interrogation pulses from the aircraft and reception of corresponding reply pulses from a ground transponder. The ground transponder is typically located near the stop end of the runway collocated with the approach azimuth system. An L-Band Distance Measuring Equipment (DME) that is compatible with existing DME equipment and provides improved accuracy and channelization capabilities is the choice for implementation. Since the same equipment is used for approach and landing as well as enroute navigation, the airborne user can utilize the operational capabilities of MLS at significant cost savings. Lower levels of service may be obtained without DME by the use of marker beacons to indicate progress on an approach.

The U.S. has also developed a C-Band DME. While it is the U.S. view that every effort should be made to utilize L-Band DME for the MLS ranging function, C-Band DME remains as an element of the MLS signal format in the event that L-Band DME cannot be implemented. Should it be decided later that

there is no need for C-Band DME, appropriate deletions from the signal format can be made.

FLARE GUIDANCE

The TRSB signal format includes a flare element (E1-2). Flare elevation equipment was tested in the U.S. MLS development program to demonstrate the feasibility of providing such a signal. A Ku-Band system was developed in the United States and a C-Band system in Australia. It is considered that C-Band is the appropriate choice, as it offers major economies.

DATA

TRSB has an extensive data capability. Data is transmitted to all aircraft within the coverage sector (FIGURE A-1) using Differential Phase Shift Keying (DPSK) modulation. Essential data is included in function preambles. It is decoded by all user aircraft. Basic and auxiliary data are time-multiplexed with the angle functions and contain information for more complex services such as missed-approach and curved paths. This information includes the status of the ground equipment and siting geometry. Considerable growth potential is available in the data format.

APPENDIX B

ANALYSIS OF ADDITIONAL CASES OF MLS CONFIGURATIONS/ERROR BUDGETS

In the duration of this effort, a few additional cases of MLS configurations and error-budgets remained under consideration on a tentative basis. This appendix presents the interference threshold analysis carried out for the additional cases of MLS configurations error-budgets labeled as 'Case 1' and 'Case 2'.

TABLES B-1 and B-2 describe these cases in terms of nomenclature of MLS configurations associated guidance functions, antenna beam widths and CMN error budgets. It may be noted that Case 1 has a larger number of MLS configurations and functions compared to the Case 2. Furthermore, Case 1 has CMN error budget prescribed for RF interference only whereas Case 2 has error budget allocated for RF interference as well as system aberrations.

Case 1 Interference Analysis

The adjacent-band analysis of Case 1 MLS configurations was based on TABLE B-1 data and Equations 1, 2 and 3 of Section 2. The interference threshold results at function level are listed in TABLE B-3. These results indicate that at function level, the desired scan beam (azimuth function) channel of the MLS Small Community configuration is more vulnerable to interference especially from the undesirable preamble/data signals. The D/U values at system level may be obtained by combining the results of TABLE B-3 with the adjustment factor X (TABLE 5) and using Equation 4. The assumption made in this approach will be that ERP data of MLS full capability configuration and minimum capability configuration are synonymous with that of MLS Expanded/Basic and Small Community configurations, respectively.

The cochannel interference analysis was based on Equation 8 and TABLE B-1 data. The D/U results at function level are listed in TABLE B-4. In this case, the Small Community and Basic MLS configurations are more susceptible to RF interference at function level.

TABLE B-1

CASE 1: MLS CONFIGURATIONS, FUNCTIONS, ANTENNA BEAMWIDTHS (ψ) AND CONTROL MOTION NOISE (CMN) ERROR BUDGET[xx]

Function		Expanded	Configuration Basic (Wide Aperture)	Basic (Narrow Aperture)	Small Community
Azimuth	ψ	1°	1°	2°	3°
	CMN[a]	.04°	.04°	.08°	0.1°
Elevation	ψ	1°	1°	1.5°	2°
	CMN	.05°	.05°	.05°	0.1°
Flare	ψ	0.5°	N/A	N/A	N/A
	CMN	0.2°	N/A	N/A	N/A
[b]Back Azimuth	ψ	3°	N/A	N/A	N/A

Note: NA = Not Applicable.

[a]CMN budget due to RF interference

[b]Back azimuth refers to guidance for "missed approach"

TABLE B-2

CASE 2: MLS CONFIGURATIONS, ANTENNA BEAMWIDTHS (ψ) AND CMN ERROR BUDGET

Function		Configuration Full Capability	Minimum Capability
Azimuth	BW	1°	3°
	Case 2 CMN	0.05°[a] & 0.2°[b]	0.05°[a] & 0.2°[b]
Elevation	BW	1°	1°
	Case 2 CMN	0.05° & 0.2°	0.05° & 0.2°

[a]CMN budget due to RF interference.

[b]CMN budget due to system aberrations.

[xx]National Plan for Development of Microwave 'anding System, FAA-ED-07-2A, June 1978.

TABLE B-3

CASE 1: FIRST ADJACENT-CHANNEL INTERFERENCE THRESHOLDS AT FUNCTION LEVEL

Type of Interaction	D/U @ Processor Terminal 1[d] (dB)	D/U @ IF Stage Terminal 2[d] (dB)	D/U @ Receiver Input Terminal 3[d] (dB)
1. Expanded and basic (Wide) Configuration			
		Azimuth Function	
U_{SN}-vs-D_{SN}	17.6	10.0	-35.0
U_{PD}-vs-D_{SN}	17.6	10.0	-21.2
		Elevation Function	
U_{SN}-vs-D_{SN}	14.0[a]	6.4	-38.6
U_{PD}-vs-D_{SN}	14.0	6.4	-24.8
		Flare Function (Expanded Configuration Only)	
U_{SN}-vs-D_{SN}	14.0	5.3	-39.7
U_{PD}-vs-D_{SN}	14.0	5.3	-25.9
		Preamble/Data Function	
U_{SN}-vs-D_{PD}	N/A	7.0[b]	-38.0
U_{PD}-vs-D_{PD}	N/A	7.0	-24.2
2. Basic (Narrow Aperture) Configuration			
		Azimuth Function	
U_{SN}-vs-D_{SN}	17.6	10.0	-35.0
U_{PD}-vs-D_{SN}	17.6	10.0	-21.2
		Elevation Function	
U_{SN}-vs-D_{SN}	14.4	6.8	-38.2
U_{PD}-vs-D_{SN}	14.4	6.8	-24.4
		Preamble/Data Function (Same as in Section 1)	
3. Small Community Configuration			
		Azimuth Function	
U_{SN}-vs-D_{SN}	19.2	11.6	-33.4
U_{PD}-vs-D_{SN}	19.2	11.6	-19.6
		Elevation Function	
U_{SN}-vs-D_{SN}	14.0	6.4	-38.6
U_{PD}-vs-D_{SN}	14.0	6.4	-24.8
		Preamble/Data Function (Same as in Section 1)	

[a] A ratio of 14 dB is an essential prerequisite for the processor to handle any information in a single scan in the SN channel. (Bendix Co.; Internal Memorandum No. MLS-ICAO-077, December 1978).

[b] A ratio of 7 dB is essential for satisfactory processing of information in the PD channel. (Bendix Co.; same reference noted above).

[c] N/A - not applicable.

[d] See FIGURE 1, for terminal identification.

TABLE B-4

CASE 1: COCHANNEL INTERFERENCE THRESHOLDS

Configuration	Function	Constraining D/U (dB)
Expanded and Basic (Wide Aperture)	Azimuth	21.9
	Elevation	20.0
	Flare	21.9
Basic (Narrow Aperture)	Azimuth	21.9
	Elevation	23.5
Small Community	Azimuth	23.5
	Elevation	20.0

The cochannel interference analysis was based on Equation 8 and TABLE B-1 data. The D/U results at function level are listed in TABLE B-4. In this case, the Small Community and Basic MLS configurations are more susceptible to RF interference at function level.

These results may also be transformed to system level D/U ratios employing the previously discussed procedure.

Case 2 Interference Analysis

The Case 2 MLS configurations and associated parameters are given in TABLE B-2. The data of TABLE B-2 along with Equations 1, 2 and 3 of Section 2 were used for determining the interference thresholds at function level and the results are listed in TABLE B-5. These results can be transformed to system level D/U ratio employing the previously discussed procedure.

The cochannel interference analysis was based on Equation 8 and TABLE B-2 data. The calculations show that the function level D/U ratios for the desired Full Capability and Minimum Capability MLS configurations are 20 dB and 29.5 dB, respectively. The function level D/U values can be readily transformed into the system level D/U values.

TABLE B-5

CASE 2: FIRST-ADJACENT-CHANNEL INTERFERENCE THRESHOLDS AT FUNCTION LEVEL

Type of Interaction	Desired Function	D/U (dB) Minimum Capability Configuration	Full Capability Configuration
U_{SB}-vs-D_{SB}	Azimuth	-27.4	-36.9
U_{DP}-vs-D_{SB}	Azimuth	-13.4	-22.9
U_{SB}-to-D_{SB}	Elevation	-32.2	-41.7
U_{DP}-vs-D_{SB}	Elevation	-18.2	-27.7
U_{SB}-vs-D_{PD}	Preamble/ Data	-38.0	-38.0
U_{PD}-vs-D_{PD}	Preamble/ Data	-24.0	-24.0

APPENDIX C

TACAN, CONVENTIONAL DME AND PDME SYSTEMS

TACAN/DME DESCRIPTION

The TACAN, conventional DME and PDME equipment operate in the L-Band frequencies. The DME, using the 960-1215 MHz band, is the internationally accepted means used by a pilot or navigator to determine the slant range between the aircraft and a known ground location. In the United States, the DME ground station is usually integrated with the VHF Omnidirectional Radio Range (VOR). TACAN, a U.S. military and NATO navigation system, incorporates the international DME with a bearing determination system and operates in the 960-1215 MHz band.[9] A DME ground station can also be associated with an Instrument Landing System (ILS) installation as the subsystem that provides the pilot with distance to the runway. TACAN/DME operation requires an interrogator in the aircraft and a transponder on the ground. Slant range to the ground station is obtained by interrogating the transponder with a pulse pair with the proper spacing. The transponder receives and decodes each interrogation and transmits a reply of a pulse pair of the proper spacing. The interrogator receives the reply and determines the distance, based on the time between transmission of the interrogation and the reception of the reply including the delay in the transponder. Distance in nautical miles is displayed to the pilot after several returns are correlated.

The interrogator determines the range to the ground station based on replies to its interrogations. The interrogation rate, is at most, 30/second except when initially trying to obtain distance information from the transponder. In this search condition, the rate may reach a maximum of 150/second. Since, as discussed subsequently, the transponder transmits at a constant duty cycle, the interrogator has the capability to identify the synchronous replies to its interrogations from the many ground station

[9] MIL-STD-291B, Standard Tactical Air Navigation (TACAN) Signal, 13 December 1967.

transmissions. To avoid mistaking replies to other aircraft interrogations or squitter pulse pairs for the desired synchronous returns, the interrogation rate of each interrogator is jittered by using a noisy source (e.g., 400 Hz line voltage) to control the rate. The bearing to the ground station from the aircraft is determined by the interrogator, based on reference signals transmitted by the TACAN or VORTAC transponder.

TACAN transponders operate with a constant duty cycle, transmitting 2700 replies/second with an additional 900 pulse-pairs/second for reference bursts. The constant duty cycle maintains the integrity of the bearing signals for 360° and also allows the interrogator AGC to adjust the receiver gain for that transponder. When no interrogators are interrogating the transponder, squitter replies are transmitted to maintain the duty cycle. As more interrogators require distance information, valid replies replace the squitter. If the total interrogation rate is such that the reply rate would exceed 2700/second, then the transponder reduces its sensitivity until the rate is maintained at 2700/second. The pulse used in these systems is usually Gaussian/cosine squared. The spectrum of the pulse transmitted from the transponder is controlled by the International Civil Aviation Organization (ICAO) specification (Reference 4).

The 960-1215 MHz band is "reserved on a worldwide basis for the use and development of airborne electronic aids to air navigation and any directly associated ground-based facilities."[10] Presently, only two systems have allocations in the band: secondary surveillance radar on 1030 and 1090 MHz, and TACAN/DME with 252 channels between 962 and 1213 MHz. Of the 252 TACAN/DME channels, half are X-mode operation and half for Y-mode operation as seen in FIGURE C-1. The terms "X-mode" and "Y-mode" indicate the characteristics of the pulse pairs, the channel frequency, and the transponder delay. (See TABLE C-1). TACAN/DME equipment X-mode has pulse-pair spacing of

[10] Manual of Regulations and Procedures for Radio Frequency Management, Office of Telecommunications Policy, Executive Office of the President, September 1976.

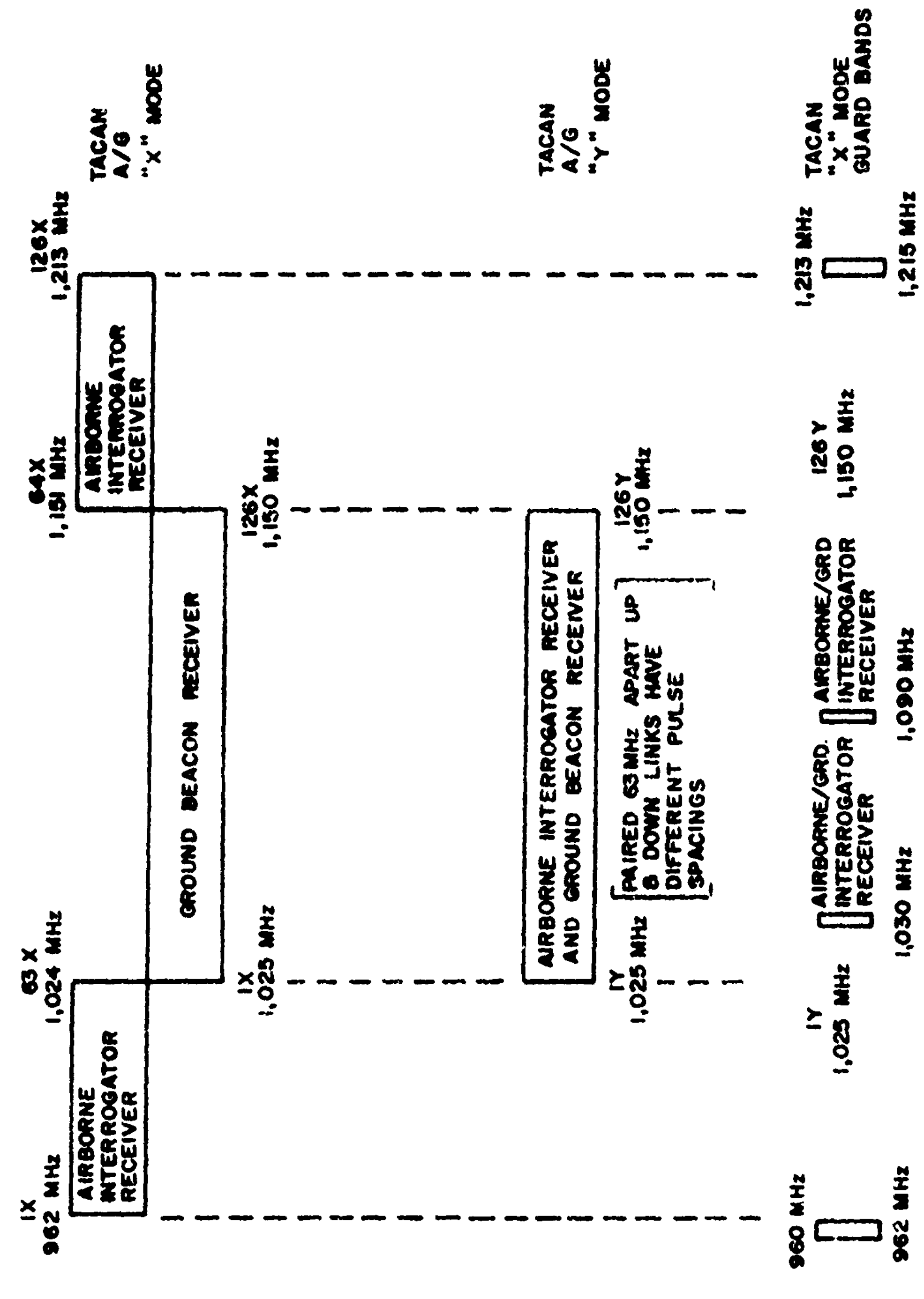

FIGURE C-1. 960-1215 MHz CHANNEL/FREQUENCY ALLOCATIONS.

12 μs for air-to-ground (A/G, interrogate) as well as ground-to-air (G/A, reply) links. The G/A frequencies are placed in 1-MHz increments between 962-1024 MHz and 1151-1213 MHz. The corresponding A/G frequencies are located in the center band, 1025-1150 MHz. The frequency separation between G/A and A/G links for a particular channel is 63 MHz.

TABLE C-1

MODES DEFINITION

Mode	Interrogator Pulse Pair Spacing (μs)	Transponder Pulse Pair Spacing (μs)	Delay In Transponder (μs)
X	12	12	50
Y	36	30	56
Z	18	30	38

PDME DESCRIPTION

PDME is based on the evolution of the DME principle. It is a multi-mode range measurement system (precision mode and enroute mode or normal mode) compatible with conventional DME and obtains increased accuracy by a pulse shape modification. At the circuit level, the precision mode differs from the enroute mode in terms of front-end stage sensitivity, bandwidth and thresholding levels at the ranging stage. It operates at L-Band frequencies between 960 MHz and 1215 MHz and on the same RF channels as TACAN and DME. TABLE C-2 lists the available PDME interrogator and transponder specifications. The channel plan eventually selected for the PDME will evolve from the PDME standardization activity presently underway with the International Civil Aviation organization.

In 1972, the FAA sponsored a program to determine the feasibility of PDME. As part of this program, analytical results were obtained which demonstrated that PDME requirements could be met within the current navigation

TABLE C-2

PDME SPECIFICATIONS[a]

Interrogator Equipment

Characteristic	Description
Operating Frequency	960-1215 MHz
Number of Channels	200
Frequency Control	2/5
Channel Tune Time	10 ms
Transmitter Peak Power	120 Watts (nominal)
Receiver Sensitivity	-74 dBm Precision mode; -84 dBm enroute mode
IF Frequency	63 MHz
IF Bandwidth	3.5 MHz Precision mode; 350 kHz enroute mode
Threshold	-20 dB & -6 dB
Acquisition Time	Less than 1 s
Dynamic Tracking	0-600 kts
Memory	(1 sec MLS)
Search Time/Cycle	Less than one second
Search PPRF	64 Hz
Track-Lock, PPRF	16 Hz(Enroute); 40 Hz (Precision)
Selectivity curves	See FIGURE 22

Transponder Equipment

Transmitter Peak Power (Watts)	100
Sensitivity (dBm)	-80
Noise Figure (dB)	10
Receiver Bandwidth (kHz)	3500
Adjacent Channel Rejection (dB)	80 (Both modes)
1st IF Frequency (MHz) (Log)	63
2nd IF Frequency (MHz)	10.7
Spurious Rejection (dB)	75
Decoder Bandwidth (kHz)	350
Time Delay Steps (s)	0.02
Wave Shape (1st Pulse)	$\cos/\cos^2$
(2nd Pulse)	$\cos\ /\cos^2$
Spurious Radiation (dB)	-60
Delay Stability (Long Term)	$\pm$0.01 μs
Frequency, Receive (MHz)	1025-1150
Frequency, Transmit (MHz)	962-1213
Emission Spectra (theoretical)	See FIGURE 21

[a] Bendix Avionics Division, Maintenance Manual, 1.B.1157B.

[b] Variable, delay and compare.

band.[11,12,13] The substance of these findings were: pulse-code multiplexing (TABLE C-1) for creating non-interfering channels; sharp rise time pulses combined with wide bandwidth processing and low thresholds for multipath immunity; and the use of the dual-mode Ferris Discriminator for simultaneous narrow-band channel selectivity and wideband selectivity and wideband signal processing.

The idea to achieve compatibility with the ICAO Annex 10 adjacent-channel specification, while simultaneously providing sharp rise time pulses, was conceived by Crow.[14] His idea was based upon a composite pulse; that is, a Gaussian-like pulse was to be superimposed upon a low-level, sharp-rise-time pulse. The low-level, sharp-rise-time pulse component confines the spectral energy while providing multipath immunity at near range where the signal level is higher. Palmeri[15] implemented the study results of Hirsch and Crow and demonstrated that their ideas were valid. The "delay and compare" pulse time-of-arrival thresholding technique, currently proposed for PDME, was first used in the U.S. MLS program by Bendix/Bell in their C-Band Phase II DME feasibility hardware. The airborne interrogator for PDME application was designed and developed by Bendix. This equipment was analyzed in terms of interference thresholds in this effort.

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[11] Hirsch, C., L-Band DME for the Microwave Landing System, FAA Contract W1-71-3086-1, Final Report, February 1972.

[12] Hirsch, C., Experimentation for Use of L-Band DME with the Microwave Landing System, FAA Contract W1-74-1245-1, Final Report, April 1974.

[13] Hirsch, C., L-Band MLS/DME Compatible with ICAO Annex 10, prepared for Automation Industries, Inc. Vitro Laboratories Division, Final Report, October 26, 2975.

[14] Crow, R., Precision L-Band DME Meeting, ICAO Format Requirements, Contract VL-SC-1170, February 20, 1976.

[15] Vitro Report, July 1975. Palmeri, C.A., Evaluation of L-Band DME for MLS, Hazeltine Report 11083.

APPENDIX D

DME AVIONICS RECEIVERS: BASIS OF ADJACENT-CHANNEL INTERFERENCE THRESHOLDS

The pulse used in radio navigational systems (e.g., TACAN, DME) has the characteristics shown in FIGURE D-1. The shape is intended to be cosine squared or Gaussian type. The spectrum of the pulse is controlled by International Civil Aviation Organization (ICAO) specification enumerated below:

"The spectrum of the pulse-modulated signal shall be such that during the pulse the effective radiated power contained in a 0.5 MHz band centered on frequencies 0.8 MHz above and 0.8 MHz below the nominal channel frequency in each case shall not exceed 200 milliwatts, and the effective radiated power contained in a 0.5 MHz band centered on frequencies 2.0 MHz above and 2.0 MHz below the nominal channel frequency shall not exceed 2.0 milliwatts. Any lobe of the spectrum shall be of less amplitude than the adjacent lobe nearer the nominal channel frequency."

A theoretical emission spectrum of the cosine square pulse, f(t), with the period t_o was derived on the following lines:

$$f(t) = \cos^2 \frac{\pi t}{t_o} = \frac{1}{2} + \frac{1}{2} \cos 2\pi \frac{t}{t_o} \qquad \text{(D-1)}$$

Now

$$t_o = \frac{2\pi}{\omega_o}$$

$$\cos \omega_o t = \left\{ \frac{e^{j\omega_o t} + e^{-j\omega_o t}}{2} \right\} \qquad \text{(D-2)}$$

From D-1 and D-2:

$$f(t) = 1/2 + 1/4\, e^{j\omega_o t} + 1/4\, e^{-j\omega_o t} \qquad \text{(D-3)}$$

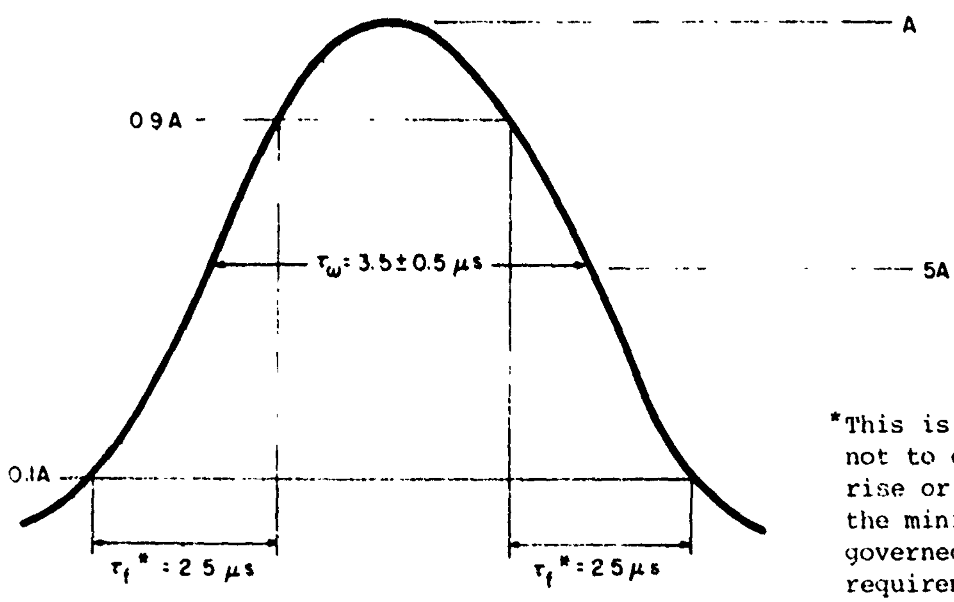
The Fourier Transform of Equation D-3 is:

$$F(\omega) = \frac{1}{\omega}\sin\frac{\pi\omega}{\omega_o} - \frac{1}{2(\omega+\omega_o)}\sin\frac{\pi\omega}{\omega_o} - \frac{1}{2(\omega+\omega_o)}\sin\frac{\pi\omega}{\omega_o} \qquad \text{(D-4)}$$

Simplifying Equation D-4

$$F(f) = \frac{\pi}{\omega_o}\,\frac{\sin\pi\frac{\omega}{\omega_o}}{\pi\frac{\omega}{\omega_o}\left(1-\left(\frac{\omega}{\omega_o}\right)^2\right)} = A_r\frac{\sin\pi f t_o}{\pi f t_o\left[1-(ft)_o^2\right]} \qquad \text{(D-5)}$$

where A_r is the constant of value $\frac{t_o}{2}$.



*This is nominal value not to exceed 3 μs; rise or fall time with the minimum value governed by the spectral requirements

FIGURE D-1. PULSE CHARACTERISTIC (TIME DOMAIN) OF AERONAUTICAL RADIONAVIGATION TRANSMITTER.

For analysis purposes, two time waveforms with half amplitude points at 3.5 microseconds and at 3 microseconds per FIGURE D-1 specifications were

considered. The rise and fall times (between 10 to 90% points) for these waveforms were 2.06 microseconds and 1.77 microseconds, respectively. The spectra for these time waveforms were calculated from Equation D-5 and these are shown in FIGURES D-2 and D-3. The calculations were also made to determine the amount of power in the adjacent channels to verify compliance with ICAO Annex 10 constraints.

The equations used for the power were:

$$P_{A1} = \frac{1}{2}\,\mathrm{ERP}\,\frac{\int_{0.55}^{1.05} F^2(f)\,df}{\int_0^{f_e} F^2(f)\,df} \tag{D-6}$$

$$P_{A2} = \frac{1}{2}\,\mathrm{ERP}\,\frac{\int_{1.75}^{2.25} F^2(f)\,df}{\int_0^{f_e} F^2(f)\,df} \tag{D-7}$$

where

P_{A1}, P_{A2} = power in the first and second adjacent channels, respectively (milliwatts)

ERP = effective radiated power from ground equipment

$F(f)$ = spectral function as derived in Equation D-5

f_e = la[illegible]quency representing trailing line of the emission spectrum.

The integration limits are obtained from the spectral specification. The sample calculations for P_{A1} and P_{A2} were made for the TACAN ground equipment with an ERP of 74.4 dBm. The results showed that for a 3.5-microsecond pulse, the power (P_{A1}, P_{A2}) in the adjacent channels was about 131 mW and .02 mW, thereby meeting the ICAO requirements.

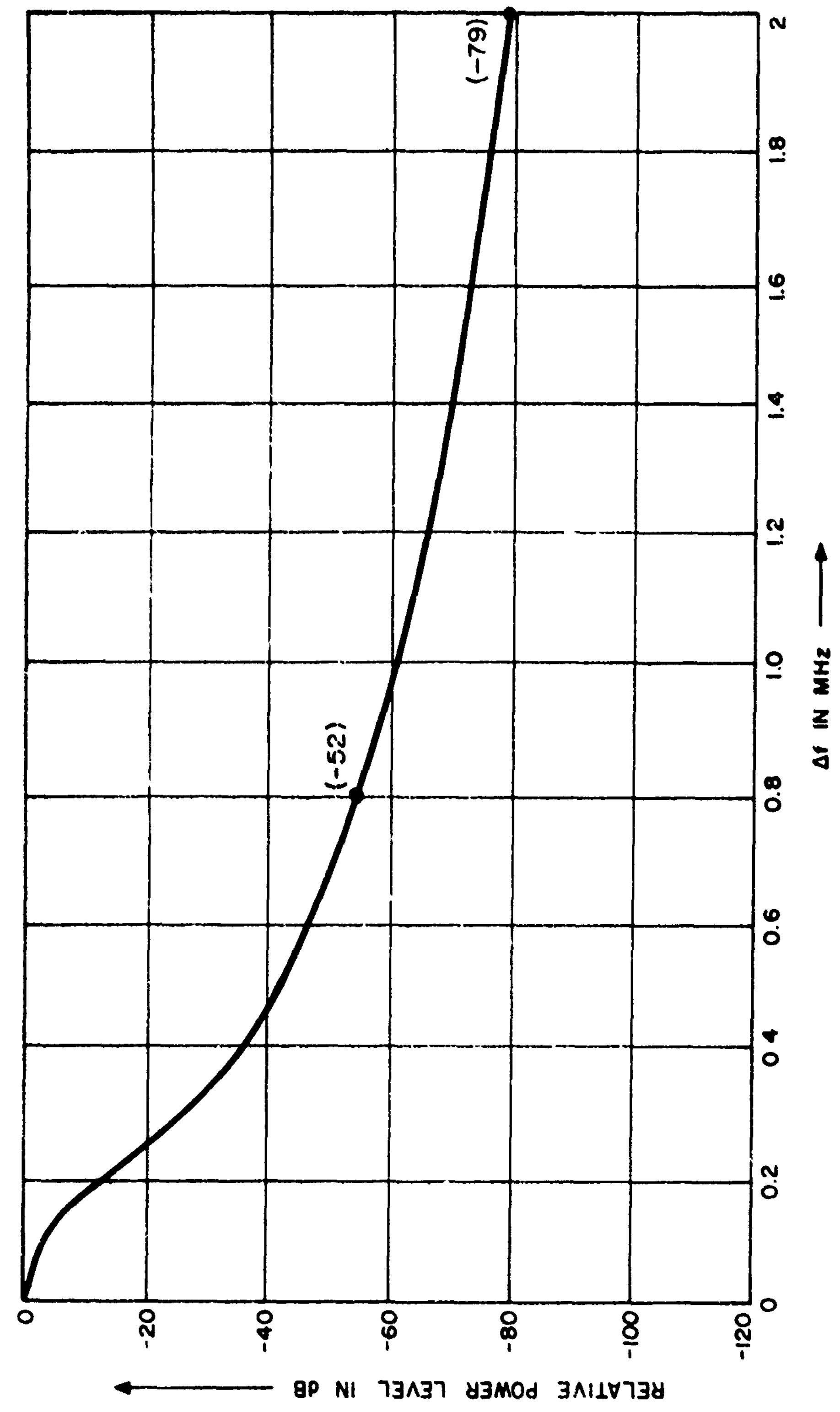


FIGURE D-2. THEORETICAL EMISSION SPECTRUM OF COSINE-SQUARE PULSE. (PULSE WIDTH 3.5 μs BETWEEN HALF AMPLITUDE POINTS; RISE TIME 2.06 μs BETWEEN 10% TO 90% POINTS.)

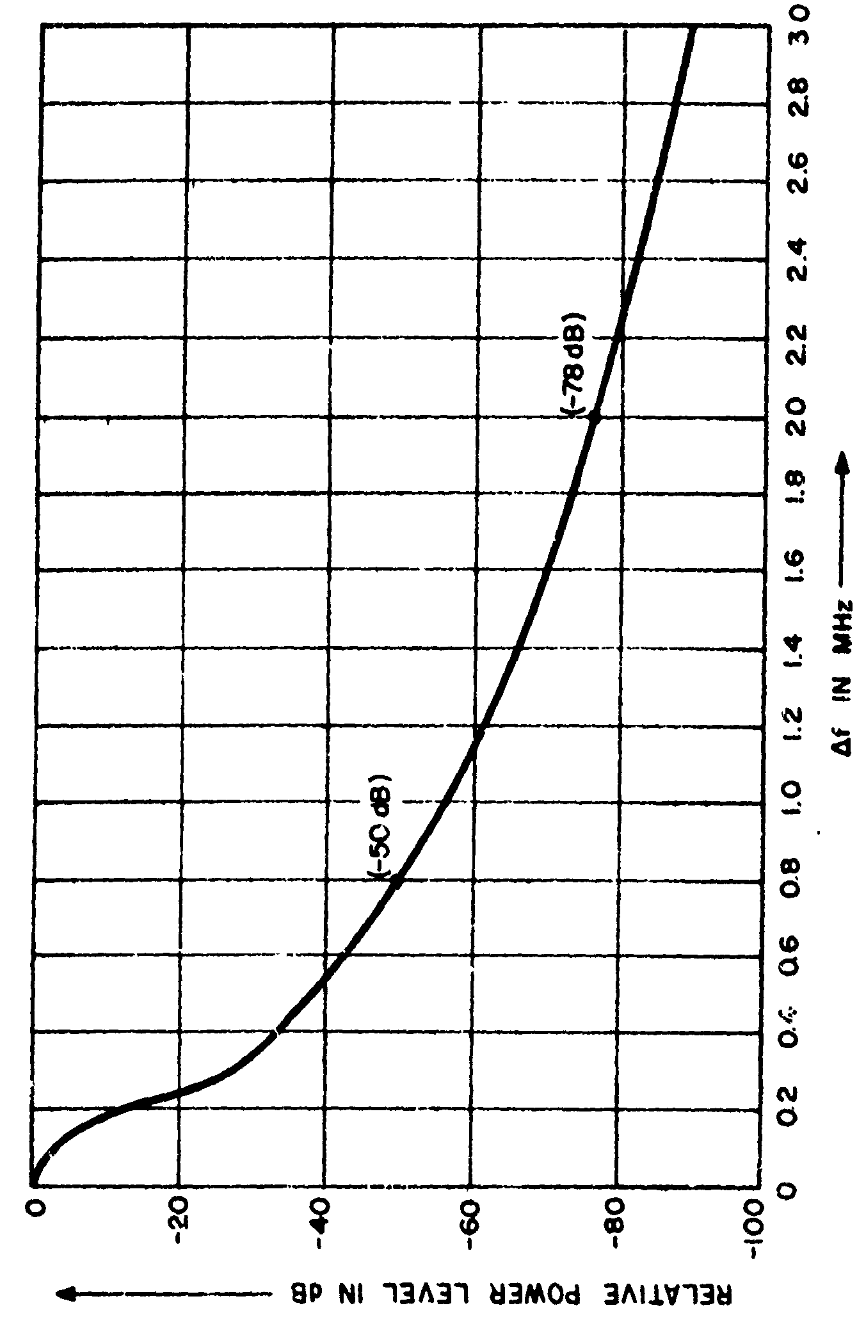


FIGURE D-3. THEORETICAL EMISSION SPECTRUM FOR COSINE SQUARE PULSE. (PULSE WIDTH 3 μs BETWEEN HALF AMPLITUDE POINTS; RISE TIME 1.77 μs BETWEEN 10% AND 90% POINTS.)

The general selectivity of the DME avionics receiver was considered to be the same as that of TACAN receivers because these receivers fall in the category of radionavigational avionics equipment. The following steps were involved in deriving the general selectivity curve.

1. The composite emission spectra of TACAN were obtained by combining a theoretical spectrum with the spectrum filter characteristics provided by FAA.[16] A sample composite spectrum is shown in FIGURE D-4.

2. An OFR plot (FIGURE D-5) was formulated based on TACAN protection rules (Reference 10). For instance, the adjacent channel protection rules D/U = -42, -50 dB with respect to on-channel power levels forms the basis of OFR plot.

3. General selectivity curves were obtained by graphically combining the composite emission spectra and the OFR plot. A sample selectivity curve is shown in FIGURE D-6.

The adjacent-channel interference thresholds for the DME avionics receiver were determined by using FORCAL[a] program. The inputs to this program were the data points from the theoretical cosine-square emission spectrum (for 3-microsecond and 3.5-microsecond pulses) and from the general selectivity curves. The results of this analysis are listed in TABLE D-1. The pessimistic OFR values for the 3.5-microsecond rise time pulse are -47.4 dB and -55.5 dB for the first and second adjacent channels, respectively. The on-channel (Category 1) interference threshold is 8 dB as derived in the previous section (TABLE ...). It implies that the interference threshold values for the first and second adjacent channel are -39.4 dB and -47.5 dB for the 1-kW DME unit. Similar results were noted for 3-microsecond rise time pulse as shown in TABLE D-1.

[16] Characteristics of TACAN Ground Transmitters Spectrum Filters, FAA, Branch ANA-320, June 19, 1979.

[a] APPENDIX E.

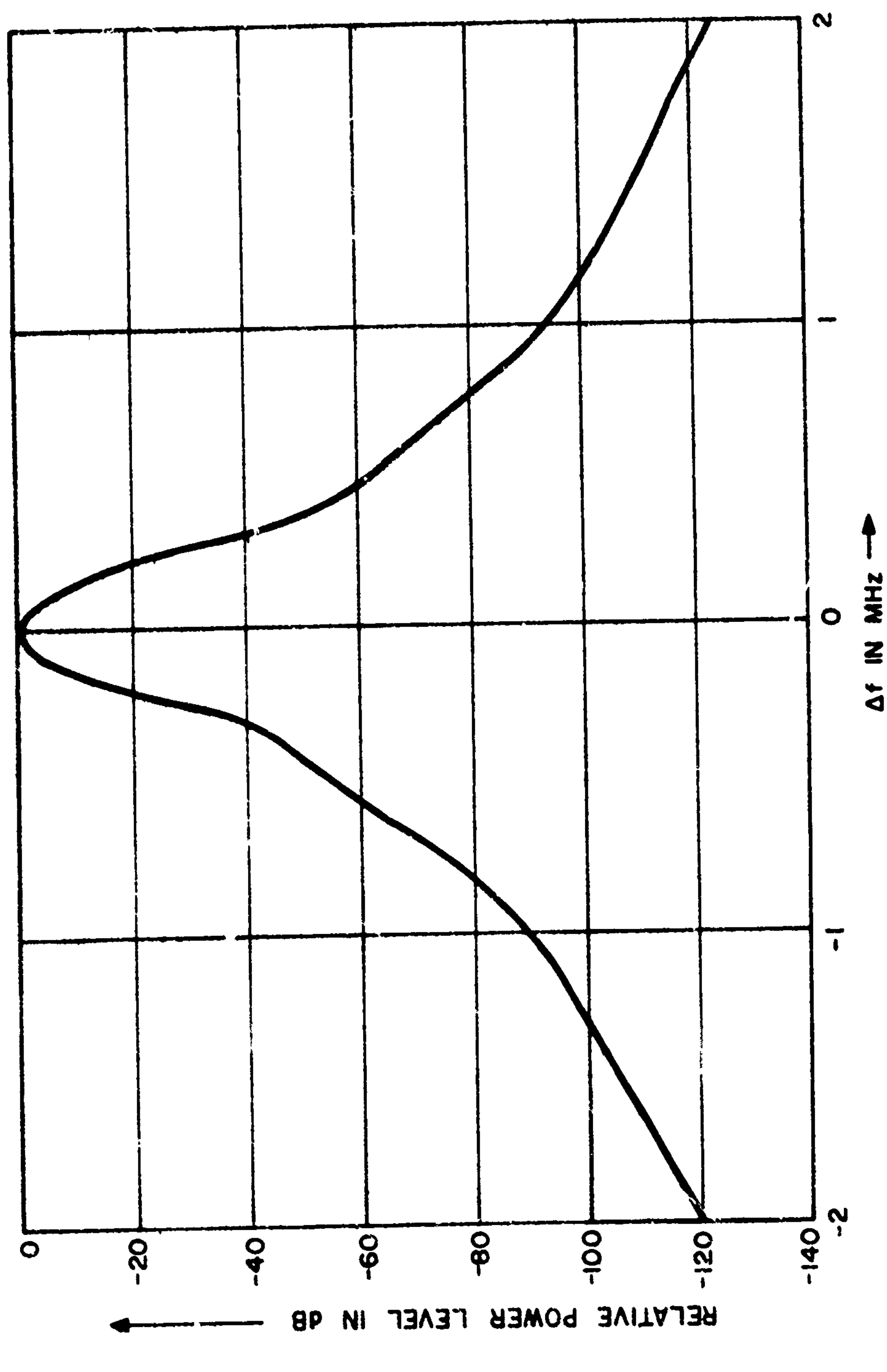


FIGURE D-4. REPRESENTATIVE EMISSION SPECTRUM FOR TACAN. (COMPOSITE TYPE; BASED ON THEORETICAL EMISSION SPECTRUM COMBINED WITH SPECTRUM FILTER CHARACTERISTICS.)

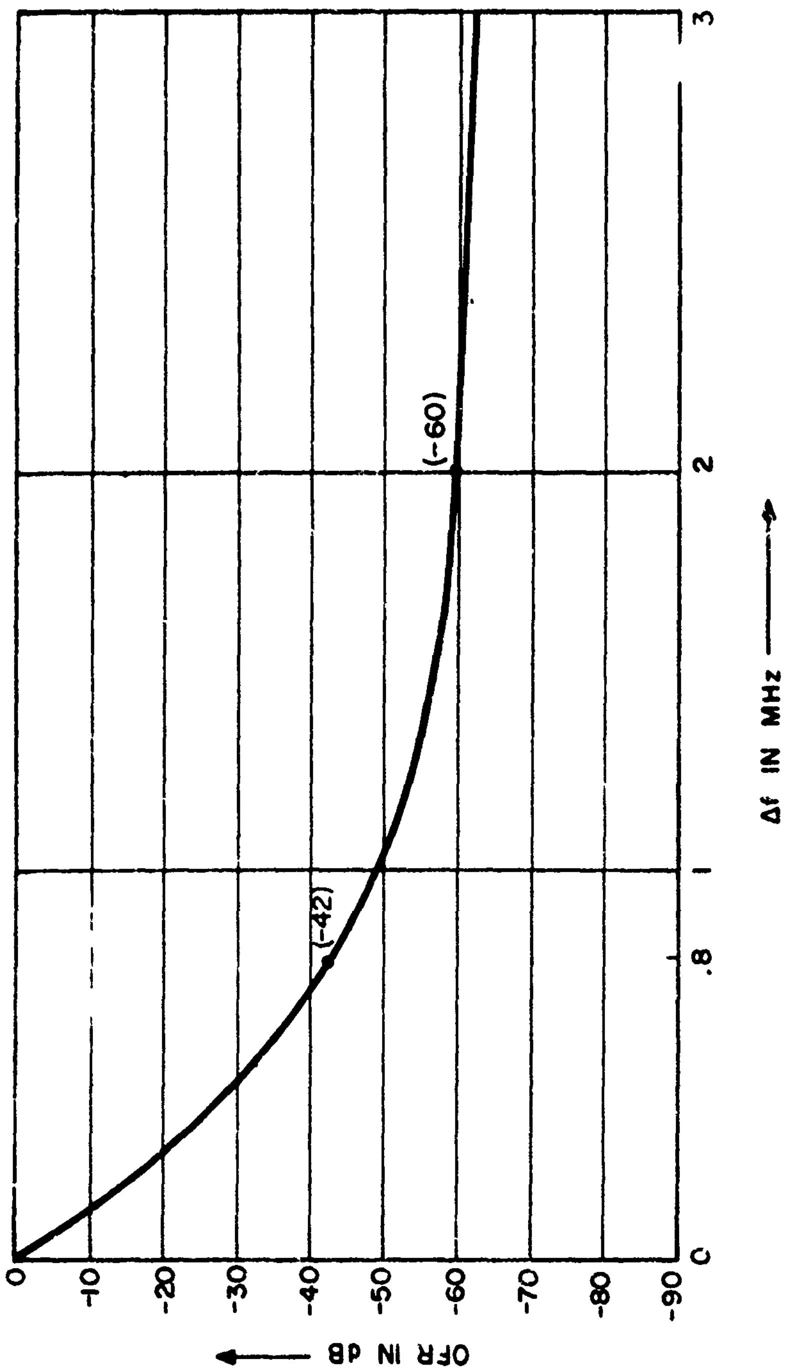


FIGURE D-5. OFR PLOT (BASED ON TACAN PROTECTION RULES).

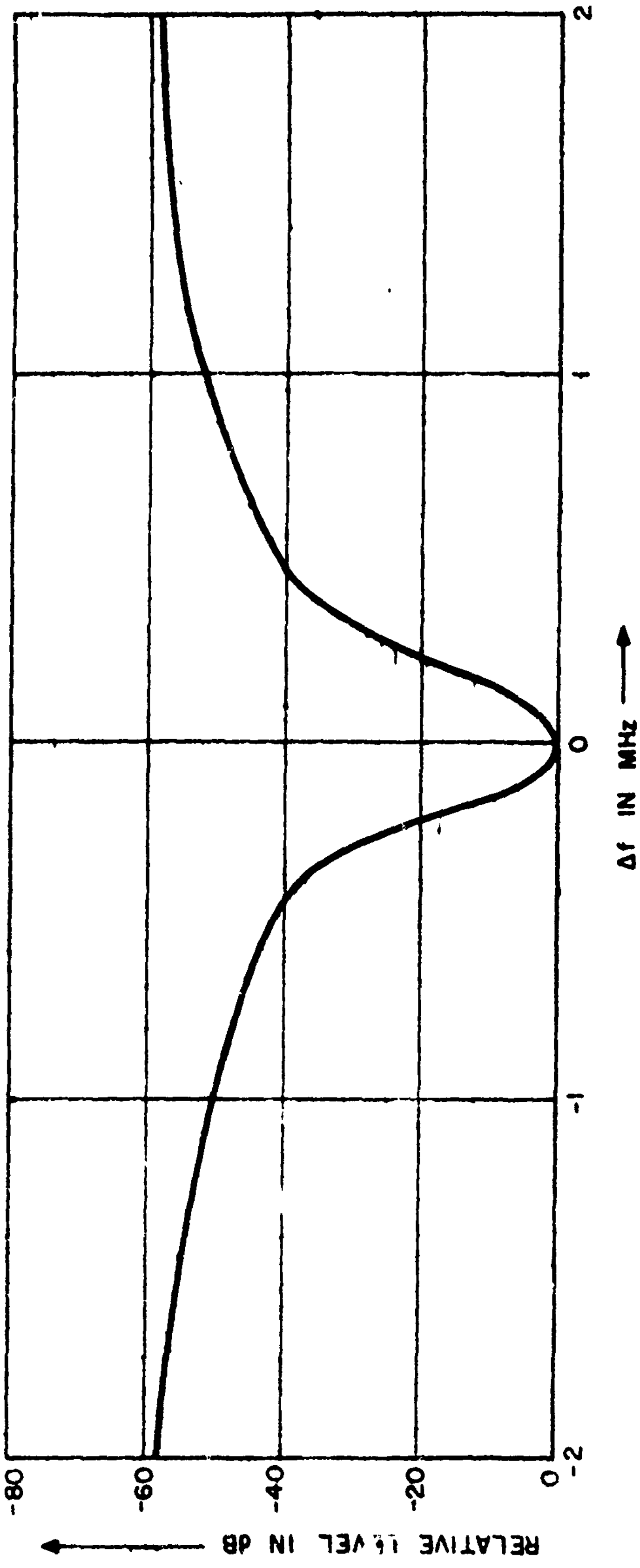


FIGURE D-6. REPRESENTATIVE SELECTIVITY CURVE FOR TACAN AND DME.

There are DME equipment (e.g. Terminal and ILS equipment) that operate with a low transmitter power of 100 watts. The preceding analysis showed that the 1-kW DME equipment did not violate the ICAO annex 10 spectral constraints (i.e. -7 dBW in the 0.5 MHz bandwidth at the 0.8 MHz frequency off-set). Furthermore the D/U ratios were determined to be -39 dB and -47 dB for the first and second adjacent channels respectively. These results suggest that with 100-watt DME equipment, it should be possible to have faster rise/fall time probe pairs and still comply with the Annex 10 constraints. The interference thresholds for the 100-watt DME equipment are -29 and -38 dB for the first two adjacent channels. It implies that the 100-watt DME has an edge of 10 dB on power basis, regarding protection from interference, over the 1-kW DME unit, provided the same pulse shape is used. This feature will negate any future frequency reassignments, should the basic DME waveform be changed for any reason.

TABLE D-1

DME AVIONICS RECEIVER: ANALYSIS RESULTS FOR ADJACENT-CHANNEL INTERFERENCE THRESHOLDS

Pulsewidth (Microseconds)	#	Representative OFR Values @ 1st Adjacent Channel (dB)	Representative OFR Values @ 2nd Adjacent Channel (dB)	Pessimistic OFR Value 1st and 2nd Adjacent Channel (dB)	Interference[a] Thresholds D/U (dB) for Adjacent Channels
3.5	1	-47.4	-55.5	-47.4, -55.5	-39.4, -47.5
	2	-47.9	-55.8		
	3	-47.7	-55.6		
3	1	-46.4	-55.2	-46.4, -55.1	-38.4, -47.1
	2	-46.8	-55.1		
	3	-47.0	-55.3		

[a]Based on on-channel D/U = 8 dB.

APPENDIX E

FREQUENCY-DEPENDENT REJECTION (FDR)

It is often useful to estimate the impact of an undesired radiating source on a potential victim receiver in terms of the power level, referred to the receiver input port, of an "equivalent" on-tune CW source (i.e., the input power level of an on-tune CW source that would result in the same average power, measured at the second detector input, as would the potential interfering transmission). In many situations, this "equivalent" input power can be compared to the receiver sensitivity or to the level of the desired carrier (also referred to the input port), to estimate the probability of interference due to that source.

The calculation of the equivalent on-tune power level is facilitated by the evaluation of a term, frequency-dependent rejection (FDR), that accounts for the fact that not all of the energy incident on the receiver input port is accepted by the potential victim receiver. FDR may be further subdivided into two terms, off-frequency rejection (OFR) and on-tune rejection (OTR). The first accounts for the loss of energy due to any detuning of the potential culprit transmitter from the potential victim receiver. The second accounts for the fact that the emission spectrum of the transmitter may be substantially broader than the receiver bandwidth so that, even if receiver and transmitter are cotuned, only a fraction of the incident energy will be accepted. The definitions for FDR, OTR, and OFR are as follows.

FDR depends on the detuning, and is the rejection provided by a receiver to a transmitted signal as a result of both the limited bandwidth of the receiver with respect to the emission spectrum and the specified detuning.

OTR is the rejection provided by a receiver selectivity characteristic to a cotuned transmitter as a result of an emission spectrum exceeding the receiver bandwidth.

OFR is the rejection, over and above the OTR, provided by specified detuning of the receiver with respect to the transmitter.

Precise mathematical definitions suitable for FDR, OTR, and OFR are as follows.

Frequency-dependent rejection, in dB:

$$FDR(\Delta f) \overset{def}{=} 10 \log_{10} \left[\frac{\int_0^\infty S(f)df}{\int_0^\infty S(f)R(f + \Delta f)df} \right] \qquad \text{(E-1)}$$

where

$S(f) \overset{def}{=}$ transmitter power density spectrum, in watts/Hz

$R(f) \overset{def}{=}$ receiver selectivity with the receiver tuned to the transmitter frequency, i.e., the on-tune CW input power required to produce a standard response, divided by the input power at frequency f required to produce a standard response

$\Delta f \overset{def}{=}$ difference between transmitter and receiver tuned frequencies, in Hz.

On-tune rejection, in dB:

$$OTR \overset{def}{=} 10 \log_{10} \left[\frac{\int_{-\infty}^{\infty} S(f)df}{\int_{-\infty}^{\infty} S(f)R(f)df} \right] \qquad \text{(E-2)}$$

Off-frequency rejection, in dB:

$$OFR(\Delta f) \overset{def}{=} 10 \log_{10} \left[\frac{\int_{-\infty}^{\infty} S(f)R(f)df}{\int_{-\infty}^{\infty} S(f)R(f + \Delta f)df} \right] \qquad \text{(E-3)}$$

Frequency-dependent rejection, in dB:

$$FDR(\Delta f) \overset{def}{=} OFR(\Delta f) + OTR. \qquad \text{(E-4)}$$

APPENDIX F

TRANSPONDERS: A GENERAL DISCUSSION OF INTERFERENCE THRESHOLDS

The national standards[17] on the VORTAC systems do not specify the performance of transponders in the presence of inter-system interference as done for the interrogators. The service provided by the transponders depends on the reply efficiency (70%) which is defined as the desired synchronous reply rate divided by the desired interrogation rate. The susceptibility of transponders to interference can be, therefore, measured in terms of reduction in the reply efficiency and the effect on the sensitivity and the dead time generated in the circuits. The aircraft traffic load enhances the interference PRF which affects the parameters mentioned above.

The typical building blocks of transponder equipment include front-end stages (RF/IF/echo-suppression), Ferris Discriminator, decoder, and biasing circuits. Therefore the analytical determination of an interference threshold for transponders will depend on knowing the characteristics of the circuits identified above. In the duration of this task, no circuit data was available on the PDME and TACAN/DME transponders. Therefore, interference thresholds for these equipments still need to be investigated.

Testing of two field models of transponders (i.e., AN/GRN-9C, RTB-2) subjected to a simulated PDME interference signal was carried out at NAFEC and reported by ECAC (Reference 6). The results of this testing are not inclusive. However, the main points of this effort are summarized below:

1. Category 1 interference (cofrequency, coaperture) generates more dead time in the receiver compared to Category 2 (cofrequency, out-of-aperature) interference. The latter primarily effects the echo-suppression circuit. Consequently, Category 1 interference has a more severe impact on transponder reply efficiency as compared to any other single characteristic.

[17] FAA-AC-00-31, U.S. National Aviation Standard for the VORTAC System, 10 June 1970.

2. A proper channel spacing is the most effective method for maintaining the reply efficiency performance of the transponders for Category 3 and Category 4 interference. This is particularly true because typical front-end stages (IF/Ferris Discriminator) in the transponders are of wide bandwidth.

APPENDIX G

COCHANNEL INTERFERENCE BASIS IN MLS ANGLE EQUIPMENT

The angle information in the TRSB/MLS equipment is determined by measuring time between the marker points on the "TO" and "FRO" scanning beams. These marker points (3 dB down with reference to beam peak) are made by the dwell gate circuits. This situation is illustrated in FIGURE G-1. The angle measurement (Θ) is given by:

$$\Theta = \text{(Scan Rate)} \times \text{(Time between "TO" and "FRO" beam)}$$

$$= \frac{\psi}{\tau} T_R \qquad \text{(G-1)}$$

where

ψ = antenna beamwidth between 3 dB points

T_R = time registered by the clock between the "TO" and "FRO" beams

τ = time to scan the beam between the beamwidth points.

A pessimistic case of cochannel interference is the in-beam interference to the scanning beam signal. The interference will modify the scanning beam shape resulting in timing-error due to shift in the beam[18] centroid. For this analysis, an interference of amplitude I is considered a perturbation to the scanning beam signal of amplitude S. The angle error ($\Delta\Theta$) due to this perturbation is expressed as:

$$\Delta\theta = \frac{\psi}{\tau} \Delta T_R \qquad \text{(G-2)}$$

[18] Kelly, R.J., "Time Reference Microwave Landing System Multipath Control Techniques," Journal of Institute of Navigation, Vol. 23, 1976.

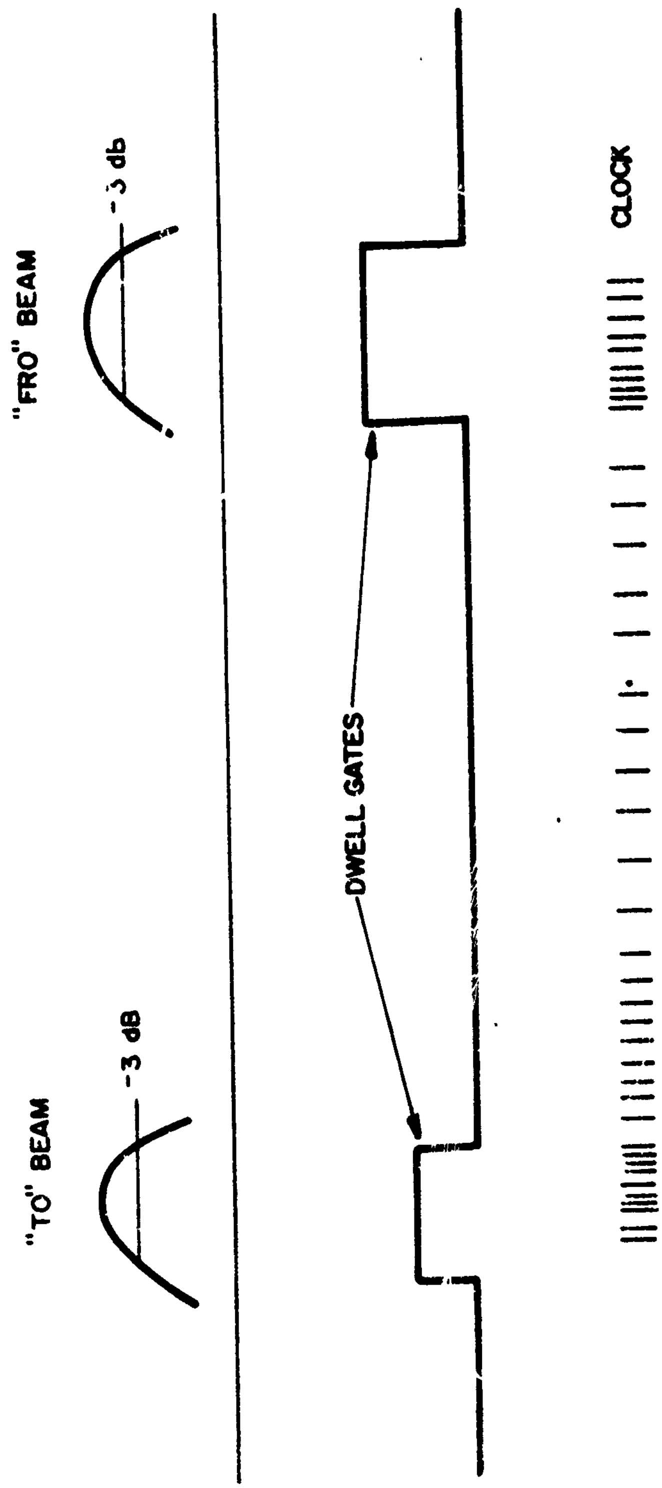


FIGURE G-1. TRSB TIME MEASUREMENT CONCEPT.

The term ΔT_R is the error in time measurement due to shift in the beam centroid because of interference. It can be related to the beam parameters S, ~ by the approximate equation:

$$\Delta T_P = \frac{\tau}{2S} I \tag{G-3}$$

From Equation G-2 and G-3,

$$S/I = \frac{1}{2} \frac{\psi}{\Delta\Theta}$$

or

$$(S/I)_{\substack{\text{Power}\\ \text{Ratio}}} = 20 \log \frac{\psi}{\Delta\Theta} - 6 \text{ dB} \tag{G-4}$$

The angle-error term $\Delta\Theta$ in Equation F-4 is associated with CMN error budget specifications of the MLS/C-Band equipment. This equation can, therefore, be used for cochannel interference anlaysis to a first-order approximation for the C-Band equipment.

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